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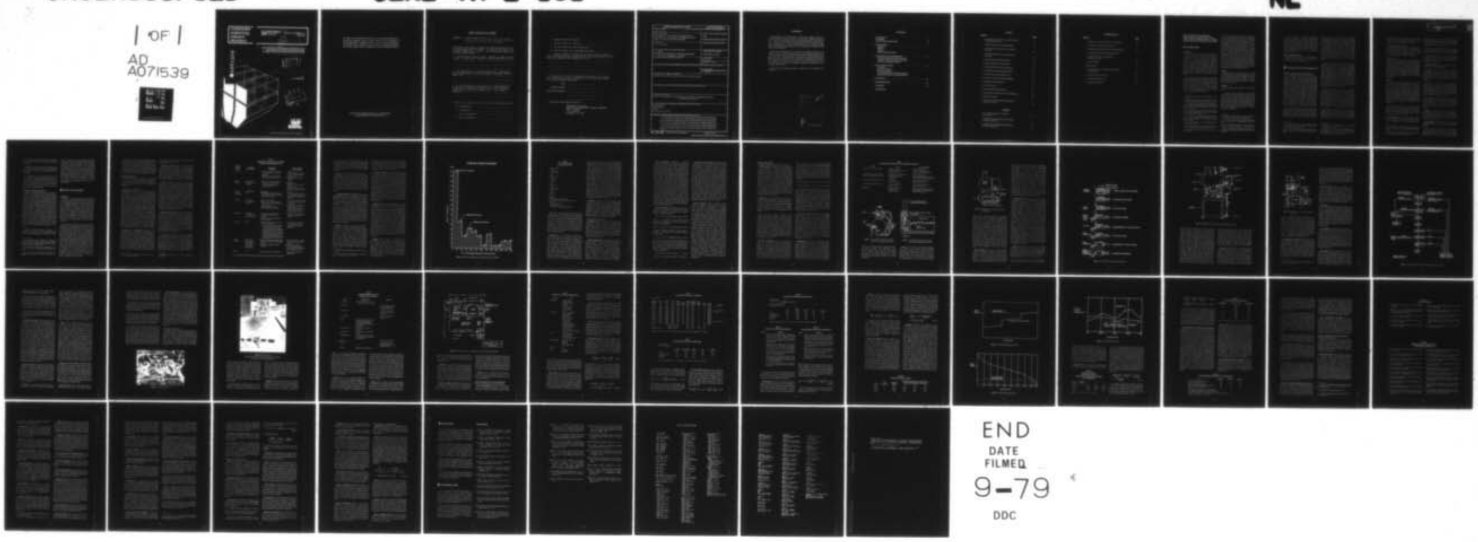

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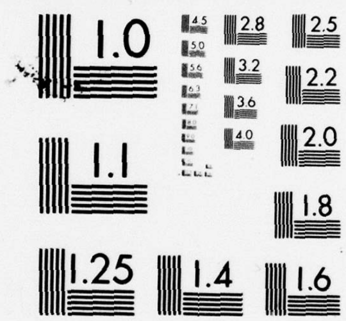

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TECHNICAL REPORT E-151
June 1979

49 p.

APPLICATION OF THE PACKAGE CONTROLLED-AIR, HEAT-RECOVERY SOLID WASTE INCINERATOR ON ARMY FIXED FACILITIES AND INSTALLATIONS

CERL-TR-E-151

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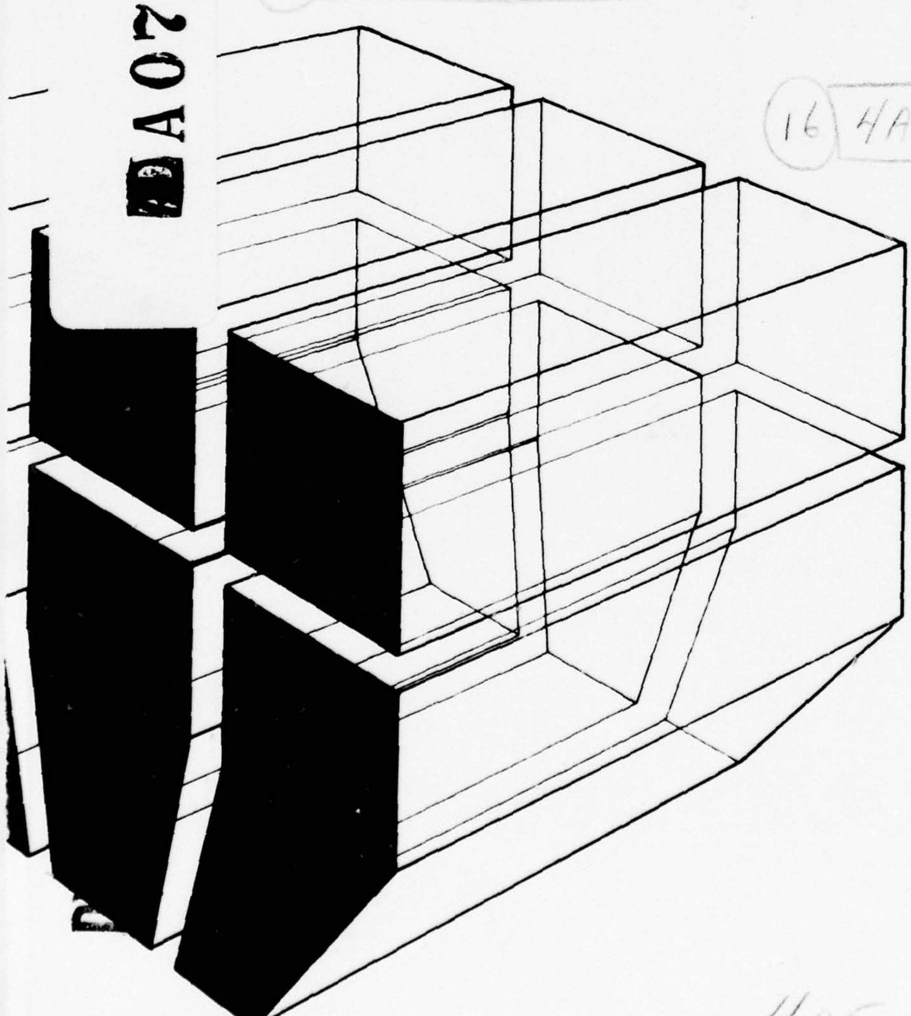

by
S. A. Hathaway

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4. TITLE (and Subtitle) APPLICATION OF THE PACKAGE CONTROLLED-AIR, HEAT-RECOVERY SOLID WASTE INCINERATOR ON ARMY FIXED FACILITIES AND INSTALLATIONS		5. TYPE OF REPORT & PERIOD COVERED FINAL 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) S. A. Hathaway		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005, Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4A763734DT09-T1-002
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE June 1979 13. NUMBER OF PAGES 47
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

incinerators
solid waste
fuels
military facilities

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This investigation evaluated use of the controlled-air, heat-recovery solid waste incinerator at Army fixed facilities and installations. Major equipment and unit operations, technical limitations, and implementation risks are discussed. The study recommends that Army use of the controlled-air system be accompanied by a thorough instrumentation and performance monitoring effort in order to better define expected technical and economic system parameters. This report furnishes technical and economic guidance that Facilities and District Engineers can use to develop projects using the controlled-air system.

FOREWORD

This investigation was performed by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A763734DT09, "Energy Systems"; Task 1, "Energy Systems"; Work Unit 002, "Demonstration of Use of Package Incinerators for Energy Recovery." The OCE Technical Monitor was Mr. B. Wasserman, DAEN-MPO-U. The CERL Principal Investigator was Mr. S. Hathaway of the Energy and Habitability Division (CERL-EH).

Appreciation is extended to Mr. P. Stone, Navy Civil Engineering Laboratory, Port Hueneme, CA; Mr. H. Kennedy, Southern Division, Naval Facilities Engineering Command, Charleston, SC; Mr. F. Hildebrand, Naval Facilities Engineering Command, Alexandria, VA; CPT R. Olfenbuttel, Civil and Environmental Engineering Development Office, Tyndall Air Force Base, FL; Mr. J. Roth, Chief of Utilities, Fort Eustis, VA; and Mr. J. Miller, Chief of Utilities, Fort Detrick, MD, for ideas which contributed to various technical portions of this report. Administrative support was provided by Mr. R. G. Donaghy, Chief, CERL-EH.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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APPLICATION OF THE PACKAGE CONTROLLED-AIR, HEAT-RECOVERY SOLID WASTE INCINERATOR ON ARMY FIXED FACILITIES AND INSTALLATIONS

1 INTRODUCTION

Background

Army interest in waste-to-energy conversion systems is motivated by the desire to conserve costly and scarce conventional fuels,[1] to conduct waste disposition operations in a more environmentally compatible manner,[2] and to minimize the costs of installation waste management.[3] Systems which are either presently or expected to be commercially available for installation use within the near term (less than 7 years) include package and site-erected, heat-recovery incinerators, and supplementary use of solid and pyrolytic gaseous refuse-derived fuel (RDF) in existing boilers.[4]

Site-erected heat-recovery incinerator systems have a well-established history of successful operation and may be used economically at installations generating solid waste at a rate of 100 tons/day (91 mt) or more.[5,6] Conversely, use of solid RDF in existing installation-scale central boilers is several years away from conclusive demonstration,[7] and no pyrolysis systems are available commercially yet.[8]

Of the numerous package heat-recovery incinerators currently marketed, the controlled-air configuration has the longest operations history (about 7 years) and is felt to have high potential for installation use.[9,10] Accordingly, the Army has planned to use several controlled heat-recovery systems during the next 4 years and has encouraged installations to continue developing projects for reclaiming energy from solid waste.[11,12] Project development efforts frequently have been inhibited both by lack of technical/economical data on controlled-air systems and by apparent conflicts between actual equipment performance in the field and the performance claimed by manufacturers and vendors. These problems have made apparent the need to provide Facilities and District Engineers with current conceptual information and technical/economic data for developing projects using the controlled-air, heat-recovery incinerator system.

Objective

The objective of this investigation was to provide conceptual information and technical/economic data for use by Facilities and District Engineers in developing waste-to-energy conversion projects at Army fixed facilities and installations using the controlled heat-recovery incinerator.

Approach

This investigation was conducted in the following steps:

1. Design concept information and technical/economic data on the controlled-air, heat-recovery incinerator were gathered from the following major sources: literature review; manufacturers and vendors; field inspection of operating municipal plants; research being conducted by Navy, Air Force, Department of Energy, and U.S. Environmental Protection Agency; and architect/engineers experienced in waste-to-energy systems (Chapter 2).

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[1] *Army Energy Plan* (Headquarters, Department of the Army, 1978).

[2] *Improving Military Solid Waste Management: Economic and Environmental Benefits* (General Accounting Office, 1977).

[3] S. A. Hathaway, *Recovery of Energy from Solid Waste at Army Installations*, Technical Manuscript E-118/ADA044814 (U.S. Army Construction Engineering Research Laboratory [CERL], August 1977).

[4] S. A. Hathaway and R. J. Dealy, *Technical Evaluation of Army-Scale Waste-to-Energy Systems*, Interim Report E-110/ADA042578 (CERL, July 1977).

[5] S. A. Hathaway, "Evaluation of Small-Scale Waste-to-Energy Systems," *Proceedings*, Third International Conference on Environmental Problems in the Extractive Industries, Dayton, OH (1977).

[6] LT J. Collins, "Refuse: The Urban Ore," *Military Engineer* (September-October 1977).

[7] *A Field Test Using Coal: d-RDF Blends in Spreader Stoker Fired Boilers* (Systems Technology Corps., 1978).

[8] "Engineers Train at Resource Recovery Session," *Waste Age* (July 1978).

[9] W. VerEecke, "Using Solid Waste Energy Sources at Military Installations," *Military Engineer* (July-August 1978).

[10] S. A. Hathaway, *Design Features of Package Incinerator Systems*, Interim Report E-106/ADA040743 (CERL, May 1977).

[11] Letter, DAEN-FEU, WASH DC, "Energy Conservation Investment Program (ECIP) Guidance" (7 November 1977).

[12] AR 420-29, *Heating, Energy Selection and Fuel Storage, Distribution, and Dispensing Systems* (Department of the Army, 1976).

2. The steps taken in the project development stages were examined for currently operating and planned facilities. This effort included methods used for waste characterization, creation of design concepts, selection of equipment, environmental considerations, and economic analysis. These data were then evaluated and arranged as step-by-step guidance to assist developing projects using the controlled-air incinerator (Chapter 3).

Mode of Technology Transfer

Guidance provided in Chapter 3 will be published as an Engineer Technical Note and incorporated into a revision of TM 5-814-5, *Incinerators*.

2 THE CONTROLLED-AIR INCINERATOR

Description of Equipment and Unit Operations

A controlled-air system consists of package, or modular, components. The major components are the furnace and heat exchanger. Modular components typically are off-shelf, predesigned, highway-shippable equipment which have a procurement time usually no greater than 8 months. Furnace and heat exchange modules are fully shop-erected and hydrostatically tested, and normally have combustion equipment and controls mounted at the factory prior to shipment. Because of size limitiations imposed by transportation criteria, the solid waste throughput capacity of the controlled-air incinerator is limited to approximately 1 ton/hour (0.91 mt/hr). Hence, the average installation, which generates solid waste at a rate of approximately 32 tons/day (29 mt/day),[13] could easily process its solid waste in a plant equipped with two incinerator-boiler lines operating three shifts/day.

The controlled-air incinerator has the longest operational history of all marketed package incinerators.[14] Also known as the "starved-air" and "pyrolytic" incinerator, it consists of a refractory-faced, stationary bed, horizontal cylindrical furnace which is batch fed up to eight times an hour during normal operation. Combustion in the furnace takes place at less than stoichiometric air. Products of this distillation process pass through an afterburning section where air and fuel are added to complete their combustion. Products of combustion then pass through a heat exchanger where either steam or hot water can be produced. While controlled-air incinerators were first manufactured in the early 1950s, their use in heat recovery is more recent, having begun in about 1972.[15] There are now more than two dozen controlled-air, heat-recovery solid waste incinerator systems in the United States.

A typical controlled-air, heat-recovery incinerator plant consists of up to five separate furnace-boiler lines. Incoming solid waste is dumped on a tipping floor and handled by a front-end loader. Plant layout includes areas or docks to accommodate bypass and bulky combustible wastes. Bypass wastes usually are hauled to disposal with ash and residue. Special low-horsepower shredders can be installed to reduce the size of bulky combustible wastes so that they can be fed to the furnaces. The tipping floor is liberally sized to accommodate surges in solid waste delivery and temporary storage as dictated by plant operating schedule and backup furnace capability.

Solid waste is fed by the loader to a hydraulic ram feeder before each furance. Charging takes place about eight times an hour, and is limited by feed hopper capacity, furnace heat release rate, and waste burnout rate. Wet and dry systems can be used for ash removal. Current plants favor wet systems, where ash is pushed by the incoming charge through an exit port in the bottom rear of the furnace to a bath. Inclined drag conveyors remove quenched ash to containers which are periodically hauled to disposal.

Air pollution control equipment is usually not included in initial construction, because currently operating controlled-air systems comply with existing particulate matter emission guidelines.[16] Nevertheless, plant designs allow for future retrofit of such equip-

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[13] S. A. Hathaway and R. J. Dealy, *Technical Evaluation of Army-Scale Waste-to-Energy Systems*, Interim Report E-110/ADA042578 (CERL, July 1977).

[14] S. A. Hathaway, *Design Features of Package Incinerator Systems*, Interim Report E-106/ADA040743 (CERL, May 1977).

[15] *Evaluation of Small Modular Incinerators in Municipal Plants* (Ross Hofmann Associates, 1976).

[16] A. Johner and E. Wisely, "Case Study—Energy Recovery from Wastes from an Automobile Assembly Plant," *Proceedings*, ASME Solid Waste Processing Conference (American Society of Mechanical Engineers [ASME], 1978).

tested while virgin water was being added to the waste in the furnace to manipulate the relative carbon dioxide (CO_2) concentration in the flue gases.

Length of Continuous Operation

Despite claims by manufacturers and vendors, the controlled-air incinerator has yet to demonstrate full-load continous 24-hour operation over more than 7 days. Therefore, it is probably imprudent to plan on full unit availability for even short-term use.

Instrumentation

Field experience to date has clearly indicated that heat-recovery, controlled-air incinerator systems are underinstrumented relative to the standards of modern incinerator practice.[24] Few plants have successfully combined instrumentation and controls for incinerators and boilers. This deficiency has inhibited progress in both scientific understanding and technical improvements, and has also left significant voids in operating and performance information required for project development.

Efficiency

Efficiency is usually expressed in terms of the fraction of input waste energy appearing in the product steam or hot water. Claims of up to 75 percent efficiency have been associated with the controlled-air, heat-recovery system, but performance to date belies such a high conversion ratio. One plant is still suffering poor burnout and is undergoing its third generation of furnace modification to reduce the carbon content of ash to tolerable levels. Efficiencies ranging between 40 and 60 percent may be more likely, but cannot be affirmed without adequate instrumentation and monitoring.

Four major areas of risk are involved when implementing a controlled-air, heat-recovery system: waste stream, facility operations, markets, and disposal.[25] Many of these risks are the same when implementing any heat-recovery incineration system.

Waste Stream. Major risk factors are waste composition, waste quantity, and technology change. Changes in waste composition can lead to reduced fraction or quality of combustibles, thus reducing fuel oil savings. Such changes also can increase the amount of unprocessable wastes which must be landfilled, thereby increasing the net cost of operations.

Reduction in waste quantity usually increases the costs of processing each ton of waste and reduces offset costs, hence decreasing return on investment.

Technological improvements in other waste disposal and resource recovery areas can reduce the quantities of available waste if a new competing processing alternative is implemented.

Facility Operations. Major risk factors are system reliability, economics, and legislation.

Reliability of the controlled-air system has not yet been established. Excessive downtime is possible, which reduces savings for fuel oil and other waste disposal activities. This can lead to temporary use of less desirable means of waste disposal, adding to total system cost.

Because of incomplete plant recordkeeping, the economics of the controlled-air system are still somewhat uncertain. It is possible, but improbable, that the cost of operations would be unreasonably high. This would require implementing alternative waste disposal systems and either discontinuing or revising whatever services relied on the heat-recovery facility.

New legislation which affects waste quality (e.g., source separation) or facility design (e.g., pollution control standards) could increase waste processing costs. In an extreme case, removing large masses of waste from the system would jeopardize its economic viability.

Markets. The major market risk factor is the potentially changing demand for the recovered product steam or hot water. Reductions in load demand may render portions of the product unusable and therefore decrease economic benefits.

Waste Disposal. The major risk factors associated with waste disposal are site capacity, site location, and legislation.

The site's capacity for disposing of ash, residue, and bypass wastes may run out before the end of facility operation, which will necessitate locating an alternative disposal site, often at an added cost. However, this

[24] S. A. Hathaway, *Design Features of Package Incinerator Systems*, Interim Report E-106/ADA040743 (CERL, May 1977).

[25] *Resource Recovery Depreciation Tax Analysis Submission* (U.S. Environmental Protection Agency, 1977).

is a low risk factor, because less waste would be involved than if there were no heat-recovery incinerator facility.

Changing the location of the ultimate disposal site for ash, residue, and bypass wastes could increase operating costs because of a longer haul distance from the facility.

New legislation may be implemented that will require design changes for landfills (e.g., liners to prevent pollution of groundwater). This can increase the cost of waste management and resource-recovery operations, but is expected to be a low risk factor because less waste would be involved than if there were no heat-recovery incinerator facility.

Limitations of Application Guidance

Derivation of the application guidance provided in Chapter 3 was hindered by lack of long-term performance data on controlled-air systems. This problem has three main origins. First, recordkeeping at operating facilities is often incomplete, thus inhibiting the assessment of mass processing and volume reduction capabilities.[26] Second, operating controlled-air systems are characteristically underinstrumented.[27] This prevents detailed evaluation of technical processes and consumption rates of auxiliary fuel, electrical power, process water, etc. Finally, industrial competition has resulted in many systems being marketed before investigative and developmental phases have been completed.[28] This has led to unnecessarily long debugging periods during which the technical character of a system changes. It has also effected so many ongoing design and manufacturing adjustments that, often, no units produced during the same month are exactly alike.

Application guidance provided in Chapter 3 is limited by the amount of information and data available when this investigation was conducted. A high degree of confidence can be associated with information provided for conceptual plant design, waste characterization efforts, and capital costs. Conversely, annual cost information specific to the controlled-air equipment consists of best current estimates and may be expected to vary within approximately 10 percent. As operating experience and breadth of performance measurement grow, more reliable project development data will become available. Accordingly, the boundary conditions of applying the controlled-air, heat-recovery solid waste incinerator at Army fixed facilities and installations will become more clearly defined.

3 APPLICATION GUIDANCE

Introduction

More than a dozen operating municipal, industrial, and military controlled-air incinerators were reviewed to obtain application data useful for developing projects at military installations. Conversations were held with management personnel as well as with manufacturers, vendors, and experienced researchers to determine how each facility was planned and implemented and to obtain as much operating and performance data as possible to incorporate into application guidance. Principal interest in the planning aspects focused on how solid waste was characterized with respect to the processing capabilities of the controlled-air system.

Two findings of this study are noteworthy. First, in planning currently operating controlled-air incinerators burning mixed trash and refuse, few efforts were made to characterize waste with respect to its daily generation rate (mass and volume), content of combustibles, general condition, and size. As a result, little is known about the flexibility of the controlled-air incinerator to process various types of waste efficiently. Second, recordkeeping at operating facilities is generally inadequate. Many facilities cannot differentiate between ignition and afterburning fuel consumption, relate power consumption to tons of waste processed, or give a detailed account of water consumption. Such data are required in cost analyses supporting project development in the military construction process. All available data were used to support the application guidance furnished here. Where data were not available, experienced estimates were used.

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[26] S. A. Hathaway and R. F. Olfenbuttel, "Comments on Johner and Wisely, 'Case Study—Energy Recovery from Wastes from an Automobile Assembly Plant,'" *Proceedings*, ASME Solid Waste Processing Conference (1978).

[27] S. A. Hathaway, *Design Features of Package Incinerator Systems*, Interim Report E-106/ADA040743 (CERL, May 1977).

[28] *Report on the Status of Technology in the Recovery of Resources From Solid Wastes* (County Sanitation Districts, 1976).

All data and estimates were assembled in a format compatible with the use of application guidance for base-level project development. Accordingly, the first few sections of this chapter review the general aspects of incineration, military solid waste generation, and combustion. Subsequent sections provide details about the techno-economic aspects of planning a controlled-air, heat-recovery solid waste incineration system.

General Considerations

This chapter provides technical and economic guidance for use by Facilities and District Engineers in implementing the package controlled-air, heat-recovery solid waste incinerator at Army fixed facilities and installations.*

General Aspects of Incineration

Rationale. Incineration is not an ultimate waste disposal method, but rather a relatively capital- and labor-intensive step in the disposal process in which waste bulk and putrescibility are reduced. A sound waste disposal method must prevent nuisance and health and safety hazards by controlling the following agents or causative factors: rodents, spread of pathogens, odors and air pollution, surface and ground-water pollution, and hazardous gases. A properly designed and operated sanitary landfill will achieve this goal. Incineration is normally not selected over land-filling unless it is justified, both economically and otherwise. Cost studies of alternative waste disposal methods are used to determine the most economic selection. When the least-cost waste disposal method does not meet standards, the next most economical method is selected. Low-cost alternatives to sanitary landfill include composting and hog feeding. Table 1 lists special requirements and cost factors to consider when evaluating alternative waste disposal methods.

Advantages of Incineration. Incineration has numerous advantages in waste disposal operations. It is applicable to liquid, gaseous, and solid wastes; reduces the bulk of many liquid and solid wastes by up to 98 percent; converts most organic (e.g., carbon-containing) materials to gases which are already part of the natural atmosphere and can be released directly into it; uses readily available oxygen from air as its principal chemical agent; entails chemical processes that are comparatively well understood; is readily carried out on large quantities of materials in apparatus of comparatively simple design; and liberates useful energy in the form of heat.[29]

Disadvantages of Incineration. The disadvantages of incineration include generation of noxious or toxic gases, smoke, and solid particulates; heavy dependence on the performance of mechanical equipment; applicability only to the combustible portion of a waste stream; comparatively high initial and recurring costs; and frequent dependence on skilled and talented labor for proper hardware performance and longevity.

Package incinerators are used to minimize total investment in a waste incineration system. Nevertheless, the costs of supporting facilities and auxiliaries for plants using package incinerators are often comparable to those for site- or job-erected systems of similar capacity, while preventive maintenance and repair costs are sometimes higher. Because incineration is an added step to the waste disposal process rather than a method of ultimate disposal for nearly all solid waste materials, its implementation has small impact on reducing waste collection and hauling costs and normally does not shut down landfills. Ash, residue, and bypass wastes can comprise up to 50 percent by weight of an installation's waste stream and must still be disposed of even after incineration.

Incineration With Heat Recovery. The dual purpose of heat-recovery incineration is reduction of waste and conservation of conventional heating and cooling fuels. The common principle of heat-recovery incineration systems is recovery and use of the heat liberated from waste combustion. Prospects for applying such systems at Army installations revolve around producing either low- or high-temperature hot water or steam for heating and cooling. Package heat-recovery incinerator technology is limited in steam production to no greater than 250 psig (1724 kPa) saturated.

A heat-recovery incineration system has all the advantages and disadvantages mentioned for incineration in general. In addition, because package heat-recovery incineration has an operational history of less than 5 years, there are numerous unknowns associated with long-term operation and maintenance requirements and length of functional life. This is an added disadvantage because the risk associated with using such equipment is high. Economic analyses of

*The controlled-air incinerator is also known as the "pyrolytic" and "starved-air" incinerator.

[29] *Combustion Fundamentals for Waste Incineration* (ASME, 1975).

Table 1
Requirements and Cost Factors to Consider in Refuse Disposal Method Selection

Type of Disposal Method	Wastes for Which Suitable	Requirements of Method	Factors to Consider in Cost Appraisal
Incineration	All	Large initial investment in plant with heavy dependence on mechanical equipment Requirements for nuisance prevention by isolation air pollution control	Capital costs: Furnaces, buildings, stacks, fuel storage, auxiliary equipment. Operating costs. High maintenance, labor, fuel, utilities.
Sanitary landfill	All but volatile, flammable wastes, organics	Suitable area or areas to allow use of method over a period of years. (Certainly through useful life of required equipment.)	Land cost. Equipment costs. Labor costs for operation and maintenance. Overhead: telephone, office, etc. Benefits in reclaiming useless land.
Plain fill or disposal on land surface	Noncombustibles, ashes	Suitable area. Most material will require earth cover but restrictions are less severe because organic matter is absent.	Land cost. Future use of land excavation in area where large concrete or stone pieces have been discarded is very difficult.
Composting	All organics, noncombustibles removed	Useful as road conditioner. . . . . Sufficient area for window type of composting on an enclosed mechanized type of digester. Sorting and grinding facilities. Useful outlet for finished compost.	Cost of separate collection, segregation or sorting of garbage from other refuse. Land, equipment, operation and maintenance costs. Costs of separate disposal of other refuse. Potential revenue from sale of compost, salvage of scrap, etc.
Open burning	Combustibles, trash, volatile and flammable wastes	Garbage and other smoke and odor producing material must not be mixed in. Firebreaks, water for fire fighting, etc., must be provided.	Consider only as adjunct to some method of separate garbage disposal.
Hog feeding	Garbage	Suitable market for hog food guaranteed for an extended period: a. To serve as sole supply for minimum efficient size farm (100 sows plus brood) would require an installation with complement of about 10,000 men. b. Hog feeding practices at contacting farms must meet local, state, and federal regulations (minimum requirement—sterilization by heating garbage to hold liquid component at 212°F for ½ hr).	Compare expected revenue with cost of segregation, separate handling and transportation to point of use.
Garbage grinding	Garbage, animal solids, organic wastes except lab and hospital wastes containing pathogens	Existing or proposed sewage disposal facilities must be adequate for added organic load. Sewers must have adequate transport velocities.	Capital and operating cost of additional sewage disposal facilities required. Cost of grinder installations. Cost difference between mixed refuse disposal and rubbish alone Value of added gas production.
Salvage	All	Sorting or segregation of salvage items.	Compare salvage value to extra handling costs.

(From *Design Manual—Mechanical Engineering* [Naval Facilities Engineering Command, 1975]).

package heat-recovery systems have attempted to deal with these unknowns by liberally estimating annually recurring costs (e.g., the debits of operation and maintenance) and conservatively but realistically estimating the values of benefits in terms of the latest available field data.

Characteristics of Army Solid Waste for Incineration

Definitions. The term "solid waste" includes garbage, refuse, and other solid materials resulting from institutional, industrial, commercial, and agricultural operations, and from community activities. Mining and agricultural wastes, hazardous wastes, sludges, and construction and demolition wastes are not included in this category for purposes of heat recovery incineration. AR 420-47 defines particular types of solid waste.[30]

Army-Wide Solid Waste Generation. Figure 1 shows the distribution of solid waste generation for FY76 at FORSCOM, TRADOC, and DARCOM installations. Data are in tons/day, 5 days/week basis as computed from annual cubic yardage data provided in *Facilities Engineering: Annual Summary of Operations Fiscal Year 1976.*[31] A density of 100 lb/cu yd (59 kg/m^3) was assumed to convert volume to mass data for this illustration. The average installation solid waste generation rate was approximately 32 tons/day (29 mt/day). The median (50th percentile) rate was far below at 19 tons/day (17 mt/day), and the maximum computed rate was 120 tons/day (109 mt/day). More than 75 percent of the installations generated less than 50 tons/day (46 mt/day), and more than 90 percent less than 80 tons/day (73 mt/day).

Variability. Installation waste generation displays both spatial and temporal variability. Waste characteristics will vary by installation. Simple spatial variability can result from differences in geography, climate, population, collection practice, and installation mission. The physico-chemical nature of waste also varies with time. Waste characteristics at one installation at time B usually will be different than at time A. When proper consideration is given to both spatial and temporal variability, meaningful generalizations about the Army-wide viability of heat-recovery incineration are difficult. This viability must be determined installation by installation, giving careful attention not only to the dynamics of waste characteristics, but also to the impact of the heat-recovery system on the installation's total waste management system, heating plant operations, and other site-specific factors.

Waste Characterization. Numerous methods are used to characterize military solid wastes. These methods range from desktop procedures using facility-related emission factors to resource-intensive field evaluation at all points of generation and disposal. Highest waste characterization accuracy is achieved when an intense field effort is carried out by trained personnel having long-term practical familiarity with installation waste management operations. Proper selection of incinerator plant equipment depends on accurate data. Table 2 lists the required data. Of these data, proximate and ultimate analyses and calorific values can be determined with acceptable accuracy using handbook instead of field and laboratory procedures. Other required data must be obtained from a field survey at the installation.

Installation Waste Generation Rates. The mass generation rate expressed as tons/day (customarily 5 days/week basis) and the volume generation rate (cubic yards/day) are required for accurate equipment selection and plant design. Both the average and standard deviation mass and volume generation rates should be determined through a field survey taken for no less than 25 continuous data days. A reliable mass generation rate is required to insure the validity of subsequent computations based on waste mass (such as calorific value, which is expressed as Btu/lb). Volume data are required to determine plant delivery and handling requirements and the potential impact of an incineration system in reducing the rate of landfill use. Both mass and volume data must be measured directly, and one should never be computed from the other using arbitrarily selected density factors for conversion.

Condition. Waste condition is a major factor in determining materials separation potential by zero-, low-, or high-technology methods and directly affects special handling requirements for incinerator plant design and operation. Waste quality can range from high grade (good materials separation potential, ease of handling by conventional means, good combustibility) to near-homogeneous slop of indeterminate constituency which presents difficulties in handling, storage, feeding, and burning.

[30] AR 420-47, *Solid Waste Management* (Department of the Army, 1977).

[31] *Facilities Engineering: Annual Summary of Operations Fiscal 1976* (Department of the Army, 1977).

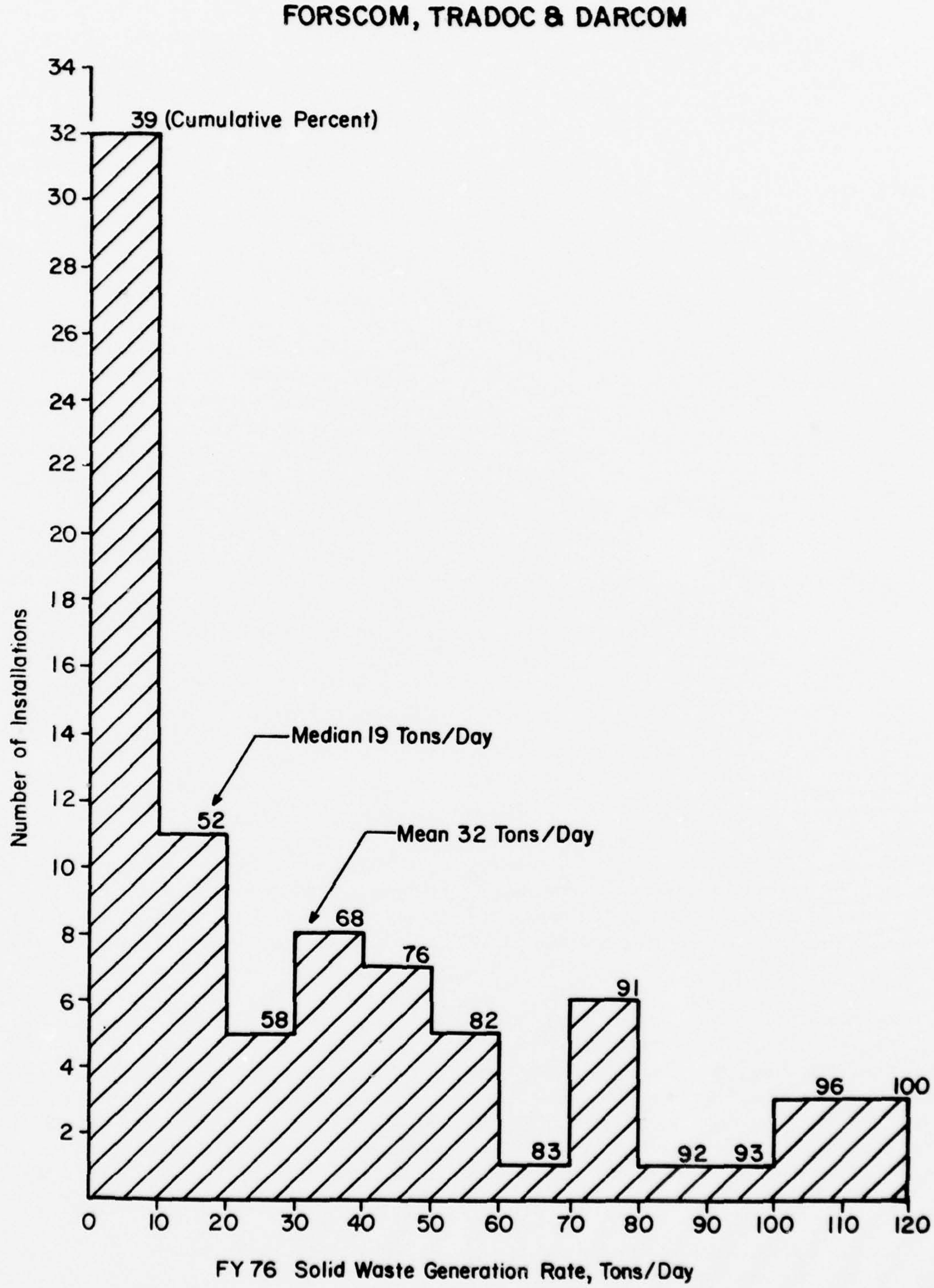

Figure 1. Scale of waste generation in three major Army commands.

Table 2
Solid Waste Parameters for Incinerator Design

Proximate Analysis
- Moisture
- Volatile matter
- Fixed carbon
- Ash

Ultimate Analysis
- Carbon
- Hydrogen
- Oxygen
- Sulfur
- Ash

Calorific Value
- Higher
- Lower (as fired)

Generation Rate
- Mass
- Volume

Condition

Size

Constituency
- Homogeneous or special wastes
- Heterogeneous wastes (mixed trash and refuse)

Predictive
- Future mission changes
- Recycle programs
- Changes in waste generating population

Size. Waste size directly affects the design of a handling system and the selection of proper incinerator plant equipment. Some combustible materials may be too large to pass through a predesigned feeder-incinerator system. In this case, it is necessary to choose whether to preprocess these materials by coarse shredding or to consider them as bypass wastes and treat them by means other than incineration. Size of input material determines not only feed hopper and furnace feed throat dimensions, but also selection of bulky materials shredders.

Constituency. It is often not so important to precisely determine the constituency of the mixed solid waste stream as it is to develop a reliable inventory of the types and quantities of homogeneous wastes generated in pure streams at the installation (e.g., cardboard, wood, ADP cards and paper, motor vehicle lubricant, exotic metals, high grade paper stock, rubber, etc.). Some homogenous wastes may have salvage value as recycled materials, depending on local market availability and on the economics and logistics of their recovery, storage, handling and marketing. The homogenous stream can be a substantial portion of the total installation waste stream and therefore can be inventoried easily. Determining the constituency of the heterogeneous mixed solid waste stream is tedious and complex. Frequently, this stream can be assumed to have an as-fired heating value that ranges from 4000 Btu/lb (9.3 mJ/kg) to 5500 Btu/lb (12.8 mJ/kg), an ash and residue content of 20 percent by weight, and a moisture content of 20 percent. Unless the heterogeneous stream is truly exceptional, these assumptions will be adequate for project development purposes. It is strongly preferable to aim waste survey efforts toward establishing accurate generation rates, condition, size, homogeneous stream inventories, and predictions of future trends, rather than to consume resources by making a detailed survey of every constituent in the heterogeneous stream. Standard procedure assumes that the waste stream is cellulose ($C_6H_{10}O_5$), which permits combustion computations to be carried out readily while preserving the essential chemical identity of mixed waste as a combination of hydrogen and carbon.

Predictions. A waste survey is not complete unless the long-term viability of its results is assessed. Planned recycling programs, possible mission change, and changes in the waste-generating population can affect the ability to predict the potential of a heat-recovery incineration system over its economic, or functional, lifetime. Not all future changes are foreseeable. Nevertheless, experienced installation personnel should address this question as definitively as possible.

General Elements Combustion

Definitions. The term "change" refers to the load of mixed solid waste fed into the incinerator. The controlled-air incinerator is fed by a hydraulic ram feeder which pushes individual charges into the primary chamber on a batch basis. In the largest package units available, (those rated 1 ton/hour (0.9 mt/hr), each charge weights approximately 250 lb (113 kg). A 1 ton/hour (0.9 mt/hr) controlled-air incinerator must be fed every 8 minutes.

Charge Composition. The chemical composition of mixed solid waste is highly complex, having an almost endless number of compounds present in the as-discarded materials. The chemical composition of material fed to the incinerator may vary greatly according to charge and the time it is incinerated. Because of the complexity and variability in the chemical nature of solid waste, it is normally assumed that the charge is cellulose, an elementary combination of hydrogen, carbon, and oxygen. This assumption facilitates the computation of combustion calculations.

Charge Combustion. Combustion is a chemical process in which the form of the charge is changed and energy is released as heat and light. Generally, solid waste burns as though it is a mixture of hydrogen and carbon in definite proportions. Several processes occur when the charge is injected into the furnace: drying, gasification (escape of volatiles), ignition, free combustion, and char burnout. Because of the highly heterogeneous nature of the charge composition, these processes usually occur simultaneously. Oxygen required to support the combustion process is supplied with combustion air, which by volume is approximately 21 percent oxygen and about 79 percent nitrogen. A very small amount of the oxygen for combustion is from the fuel itself. Carbon in the charge combines with oxygen in the combustion air to form carbon dioxide (CO_2). Hydrogen combines with oxygen to form water (H_2O), which appears as a vapor at high temperatures. Nitrogen does not contribute to the combustion process, but carries away some heat. By conservation of mass, the weight of the charge, plus the fuel and air supplied for combustion equals the weight of ash, other solid refuse, and combustion gases discharged through the stack.

Combustion Reactions. Combustion is a process of oxidation—the conversion of an element into its oxide through combination with oxygen. The complete burning of carbon is expressed as

$$C + O_2 \rightarrow CO_2 + \Delta\,(169{,}116 \text{ Btu/lb mole}) \qquad [\text{Eq } 1]$$

where Δ is the quantity of heat released in the exothermic, or heat-liberating, reaction. The complete combustion of hydrogen is

$$H + \tfrac{1}{2}O_2 \rightarrow H_2O + \Delta\,(122{,}891 \text{ Btu/lb mole}) \qquad [\text{Eq } 2]$$

Incomplete combustion results if too little oxygen is available, as exemplified by the following reaction involving carbon:

$$C + \tfrac{1}{2}O_2 \rightarrow CO + \Delta\,(47{,}400 \text{ Btu/lb mole}) \qquad [\text{Eq } 3]$$

This reaction illustrates the benefits of monitoring the presence of CO in the flue gases. CO indicates incomplete comustion and the need to increase the supply of combustion air to the furnace. The complete combustion of cellulose is given as follows for standard combustion calculations:

$$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O + \Delta' \qquad [\text{Eq } 4]$$

where Δ' is the as-fired heating value of the material.

Combustion Air Requirements. The precise amount of oxygen required for complete combustion is termed "theoretical air." In practice, however, an excess of air is required for complete combustion. The exact amount of excess air depends on furnace conditions and the material being burned. Excess air is expressed as a percentage of the theoretical air requirement; hence, 50 percent excess air is 150 percent theoretical air. Major air sources for the furnace are underfire air (through inlets beneath the fuel bed) and overfire air (injected above the fuel bed). Some oxygen is supplied through auxiliary fuel burners which fire at excess air, the waste feed inlet, and the waste itself. Stationary-bed incinerators of the controlled-air type may require up to 100 percent excess air. Less than optimal combustion air supply results in the formation of soot, or unburned carbon. When heated with insufficient air, hydrocarbons thermally decompose into free carbon and hydrogen. Heavier hydrocarbons decompose rapidly and have a lesser tendency to burn smokelessly than lighter hydrocarbons, such as natural gas.

Practical Burning. Modern incinerator design attempts to optimize time, temperature, and turbulence for combustion. A deficiency in one of these factors may often be compensated for by adjusting either or both of the other two. Some time is required to oxidize carbon to carbon dioxide (Eq 1). Insufficient charge residence time in the furnace usually results in incomplete combustion, which can be detected by the presence of carbon monxide and/or smoke in the flue gases. The rate at which the reaction takes place is governed partly by temperature. Generally, the rate increases with higher temperatures. Correcting the incomplete combustion of a charge in the furnace can require increasing temperatures, while maintaining acceptable residence times for complete combustion. In the controlled-air incinerator, allowable temperatures usually do not exceed 1600°F, (871°C) since slagging can become severely problematic above this point. Combustion can be enhanced by turbulent mixing of the charge, which continually exposes fresh surfaces to combustion air and heat radiated from the refractory. Some incinerators have mechanical stokers for this purpose; however, the controlled-air incinerator is a stationary-bed type having no mechanical equipment to agitate the charge. In this sense, the controlled-air incinerator is technically inferior to moving-bed types. Residence time and temperature are the controlling factors of operation in the controlled-air unit, with turbulence being substantially less significant.

Plant Technical Aspects

Package Controlled-Air, Heat-Recovery Incinerator

Package Systems. Package incineration systems consist of predesigned, off-shelf, highway-shippable equipment which has a procurement time usually no greater than 8 months. The furnace and heat exchange modules are fully shop-erected and hydrostatically tested; normally, their combustion equipment and controls are mounted at the factory prior to shipment. The forced draft fan may or may not be mounted, depending on the size of the equipment. Very large units (e.g., up to 1 ton/hour (0.9 mt/hr) capacity) will have at least the combustion controls mounted, but forced draft fan, feed hopper, air pollution control equipment, separate boiler (if required), ash removal equipment, stack system, and other controls may be shipped in packaged modules for field assembly with a minimum of on-site labor.

Equipment. The background of the package controlled-air incinerator originates with past generation batch-feed, brick-and-mortar, multiple-chamber incinerator. The controlled-air incinerator has been designed to eliminate problems encountered with its multiple-chamber forerunners: excessive excess air, overcharging, poor charge burnout, low maintainability, and air pollution.

The controlled-air incinerator consists of two chambers. The primary chamber is a refractory-faced, insulated, steel-clad, horizontal, cylindrical chamber to which the charge is delivered from an adjoining, front-mounted ram-feed hopper. The secondary chamber is located above the primary chamber and is also refractory-faced, insulated, and steel clad; this chamber functions as an afterburning area to provide complete burnout of distillation products from the primary chamber. Heat exchange equipment is added after the secondary chamber. Most available controlled-air incinerators are self-supporting and are insensitive to small deviations from level.

Principle of Operation. A major operational principle of the controlled-air incinerator is its ability to control the quantity and location of combustion air supplied to the unit. In ideal operation, less than theoretical air is supplied to the charge in the primary chamber. Air velocity below, through, and on top of the fuel bed is maintained below levels required to entrain particulate matter and carry it out of the primary chamber. With less than theoretical air and at temperatures up to approximately 1600°F (871°C), much of the charge is destroyed by destructive distillation, or pyrolysis (hence the alternatively used names "starved air" and "pyrolytic" incinerator). Most of the pyrolysis products are in the gas phase. Combustion is completed when additional combustion air and heat (as required) are added in the secondary chamber. The two-stage complete combustion process is shown as follows, with the burning of elemental carbon as an example.

Primary chamber: $C + \frac{1}{2}O_2 \rightarrow CO + \Delta$ [Eq 3]

Secondary chamber: $CO + \frac{1}{2}O_2 \rightarrow CO_2 + \Delta$ [Eq 5]

The controlled-air design increases the amount of time available for combustion by minimizing the volumetric flow rate of air to the primary chamber. Reducing the amount of primary chamber air reduces the amount of heat which must be added through auxiliary burners to maintain proper temperatures. The cylindrical shape of the furnace is an attempt to equalize heat radiating from the refractory material to the charge. Turbulence is maintained by proper air injection and gas baffling in the secondary chamber where burnout of gas phase pyrolysis products and solid phase unburned carbon occurs.

Unlike agitated-bed incinerators that are equipped with moving mechanical stokers, the controlled-air incinerator has no means of mixing the charge. With certain materials like sawdust, dewatered sludge, manure, animal bedding, and even extensively preprocessed mixed solid waste, there is a tendecy toward surface crusting and incomplete burnout, even with long residence times. Table 3 lists some general operational aspects of the controlled-air incinerator in terms of problems, causes, and solutions. As indicated by Table 3, time and temperature are the dominant factors in controlled-air operation. The reduced role played by charge mixing is typical of batch-fed, stationary-bed incinerators.

Configurations. Two major configurations of package controlled-air incinerators are available. The original configuration includes a vertical cylindrical secondary chamber and a vertically oriented afterburner (Figures 2 and 3). The secondary chamber is volumetrically about one-fourth the size of the primary chamber. More recent units have a larger, horizontal cylindrical secondary chamber and either a horizontal or inclined afterburner (Figure 4). The newer configuration may be more advantageous than its predecessor

Table 3
General Operational Aspects of the Controlled-Air Incinerator

Problem	Cause	Solution (Relation)
Unburned material on ash conveyor	Feed rate too high	Reduce feed rate (time)
	Insufficient primary chamber air	Increase underfire air (temp.)
	Channeling of charge	Return to original feed rate (time)
Excessive carbon in scrubber effluent	Primary chamber temperature low	Restart burner (temp.)
Smoke from stack (black, grey, brown)	Insufficient flameport air	Increase flameport air (temp., turb.)
	Burner failure	Reset burner higher temperature (temp.)
Secondary chamber temperature high	Insufficient air	Increase flameport air (temp.)
	Feed rate too high	Reduce feed rate (time)
Secondary chamber temperature low	Excessive combustion air	Decrease flameport air (temp.)
	Feed rate too low	Increase feed rate (time)
Backdrafting	Excessive combustion air	Decrease flameport air (temp., turb.)
	Draft too high	Increase damper counterweight (time)
	Feed rate too high	Reduce feed rate (time)

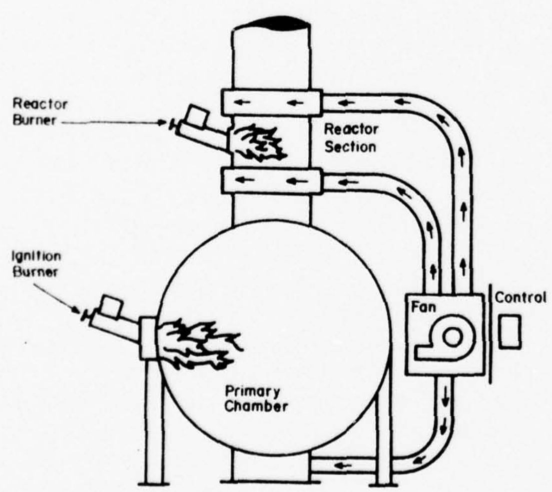

Figure 2. Controlled-air incinerator with small afterburner configuration (end view).

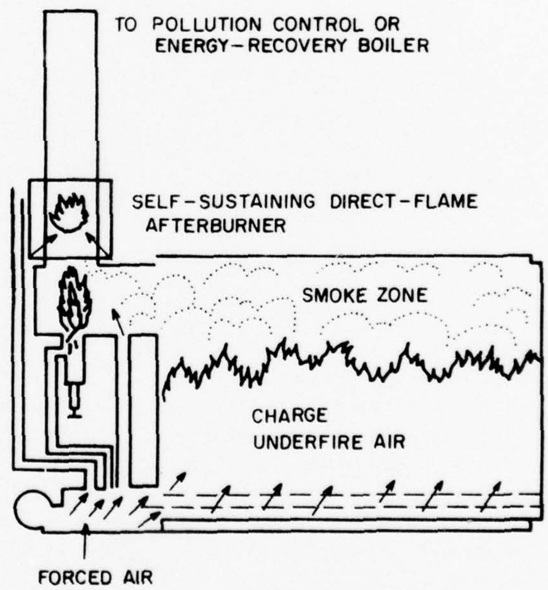

Figure 3. Controlled-air incinerator with small afterburner configuration (side view).

because the secondary chamber is equal in volume to the primary chamber. This "piggyback" design provides a greater time for burnout of combustibles from the primary chamber and has better mixing capability. No field data are available to conclude which configuration will provide better service at Army installations.

Feeders. Each of the two controlled-air configurations is fed on a batch basis by a remote-controlled, hydraulically driven ram-feeder. Figure 5 shows the feeder's general operational cycle. The cycle from hopper feeding to restart can require up to 4 minutes. Incinerators rated at 1 ton/hour (0.9 mt/hr) must be fed approximately every 8 minutes and therefore

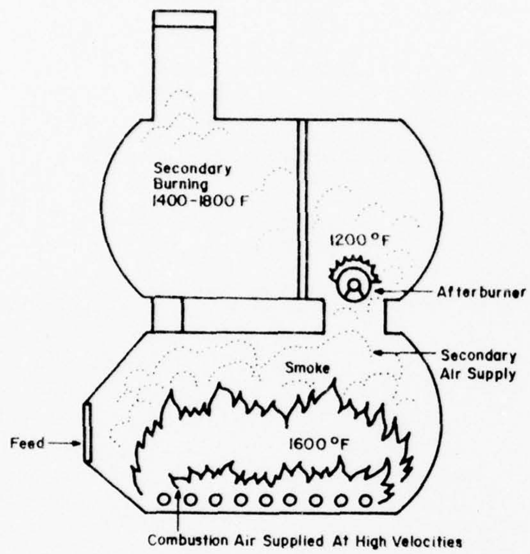

Figure 4. "Piggyback" controlled-air incinerator configuration.

require nearly constant attendance by an operator. Systems can be selected in which each major step in the feed cycle can be controlled individually or in which total cycle operation is activated by a single switch. It is recommended that a water source be installed near the fire door to quench buring materials which might be withdrawn from the primary chamber as the ram returns. The size of the waste which can be fired is limited by hopper opening dimensions, which, for 1 ton/hour (0.9 mt/hr) units, average 3.5 feet (106.8 cm) in length by 2.5 feet (76.2 cm) in width. Accordingly, if bulky combustibles are to be fired, they require coarse size reduction to enable them to pass through the feeding system into the primary chamber. Some controlled-air incinerators now have secondary, larger feed ports above the ram feeder to permit manual charging of larger waste materials.

Heat Exchangers. Two types of heat exchange systems are employed, depending on the incinerator configuration selected. In the piggyback system, combustion products pass directly from the secondary chamber to a separate package boiler. The favored boiler is a D-type watertube boiler having sootblowing capability and ash hoppers beneath the passes. Firetube boilers have been used, but have potential problems of tube plugging and accelerated wastage of tube material by corrosion and erosion. The small-chamber controlled-air configuration employs an integrated watertube section, as illustrated in Figure 6. In this system, an emergency bypass stack is provided to purge heat (Figure 7). Whichever system is selected, provision should be made to fire the boiler separately when the incinerator is off line. Although this will require additional investment, instrumentation, and control costs, boiler functional life will be extended by minimizing the cyclicity of its operation. Feedwater makeup and treatment requirements for the heat-recovery boiler are generally the same as for any package boiler. Location near an existing boiler plant or steam line may allow the use of existing feedwater preparation and product distribution facilities.

Ash Removal. Wet and dry ash removal systems are available with each controlled-air incinerator configuration. Some dry systems are truly batch; when large quantities of ash and residue have accumulated in the primary chamber, the system is cooled down, and burned-out material is removed manually through a rear hatch. More recent-model dry systems provide positive displacement of ash out a rear port to a container or concrete slab when a new charge is fed. Available wet systems quench displaced ash either by water spray or water bath. In the latter case, quenched ash is removed by inclined drag conveyor to nearby containers for regular removal to ultimate disposal. Both dry and wet displacement systems represent an effort to make controlled-air operation more continuous. The water bath system is recommended, particularly because of its reliable quenching and dust amelioration capabilities. Its disadvantages include occasional conveyor jamup, corrosion of materials, and water treatment requirements. Caution is advised when considering discharging ash quench water to a sanitary sewer, because this water contains heavy metals and has a low pH. Proper design of this system should minimize dripping of quench water from vehicles hauling quenched ash to disposal.

Utilities. Heat recovery plants should be provided with two-way electrical feed (to reduce plant outage probability), primary and standby water supply, sewer service for sanitary and process water, telephone and fire alarm lines, auxiliary fuel supply, and a means of handling the plant product (steam or hot water).

The average electrical service needed for incinerators rated at 1 ton/hour (0.9 mt/hr) includes 220-volt,

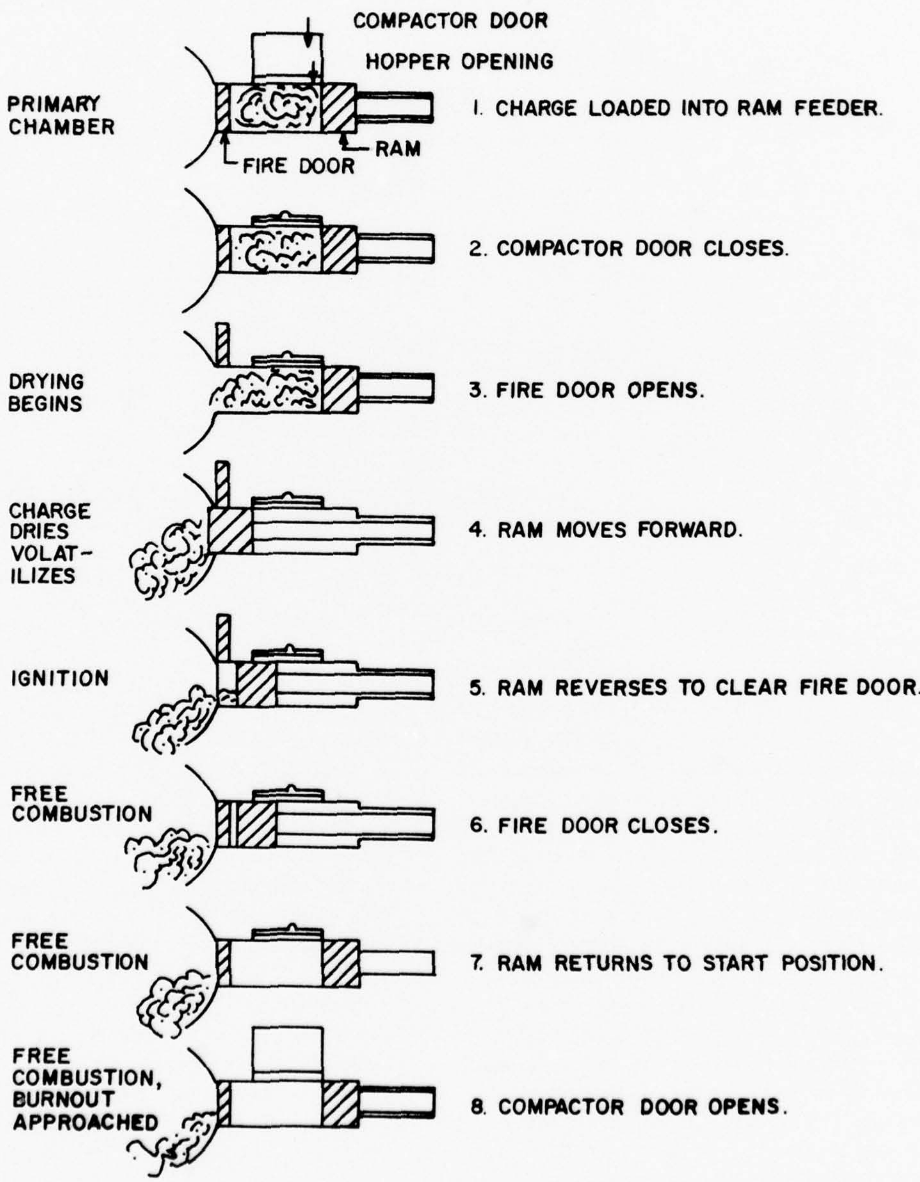

Figure 5. Controlled-air incinerator ram-feed cycle.

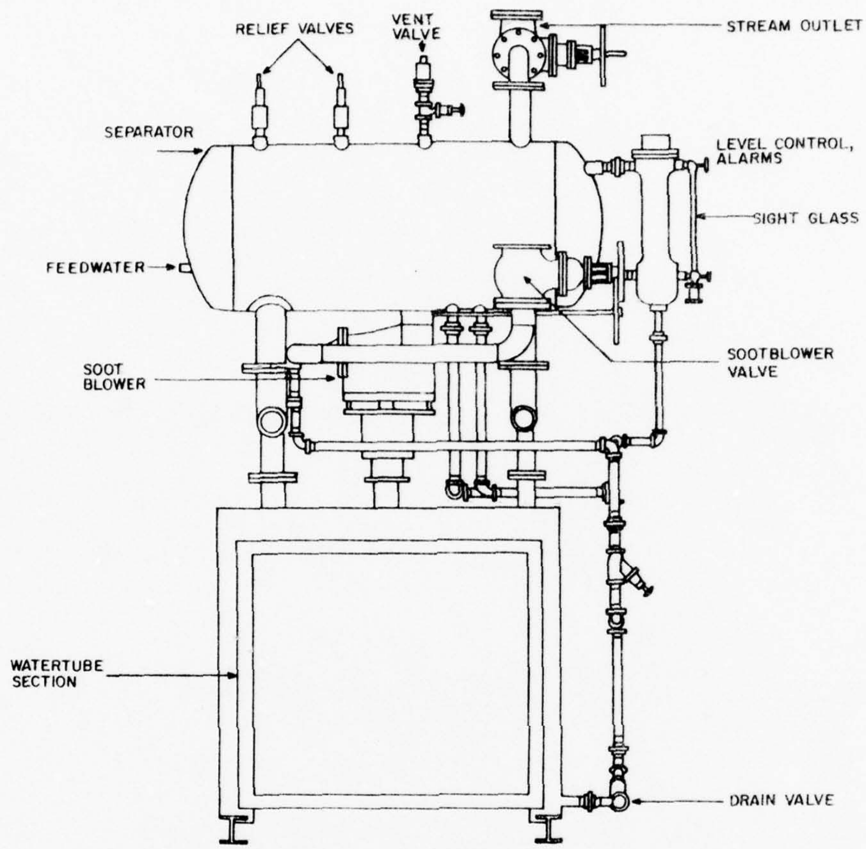

Figure 6. Modular heat exchange section on controlled-air system.

3-phase, 60-cycle, 100-amp and 110-volt, 60-cycle, 20-amp. An electrical substation is usually required. Essential equipment, controls, and instruments consume the energy produced from between 25 and 40 kWh/ton (82 and 131 mJ/mt) of waste processed. This figure can rise to 60 kWh/ton (197 mJ/mt) if waste preprocessing and air pollution control equipment are included. Natural gas, light oil, and sometimes liquid wastes can be used as auxiliary fuel. A day tank having at least a 3-day fuel supply is sometimes included in the plant design. Auxiliary fuel consumption ranges between 1.5 MBtu/ton (1.7 gJ/mt) and 3.0 MBtu/ton (3.4 gJ/mt). General plant water is consumed at approximately 20 gpm (76 ℓ/min), ash quench water up to 5 gpm/unit (19 ℓ/unit), and wet scrubber water at approximately 60 gpm/unit (228 ℓ/unit). The cost for chemical treatment to adjust the pH of quench water and/or scrubber water can average $1.25 per ton ($1.37/mt) of waste processed. A pneumatic air source is used for sootblowing, since steam lancing is fuel-intensive. Propane is required as front-end loader fuel if an indoor tipping floor system is chosen. Some plants include a steam cleaning facility for plant floor, containers, and sometimes for collection vehicles. Consumption can be as high as 8500 lb (3856 kg) per vehicle, depending on pressure, temperature, volume, and soiling conditions. Cleaning media are usually mixed with detergents, deodorants, and insecticides.

Maintenance. Routine and cyclic preventive maintenance and repair requirements of the package controlled-air, heat-recovery system are not well known because of its relatively brief operational history. It is widely agreed, however, that without intensive upkeep the system will not have a functional life comparable to that usually associated with semi-permanent and permanent facilities. Repair, or the anticipated replacement of major components during the amortization

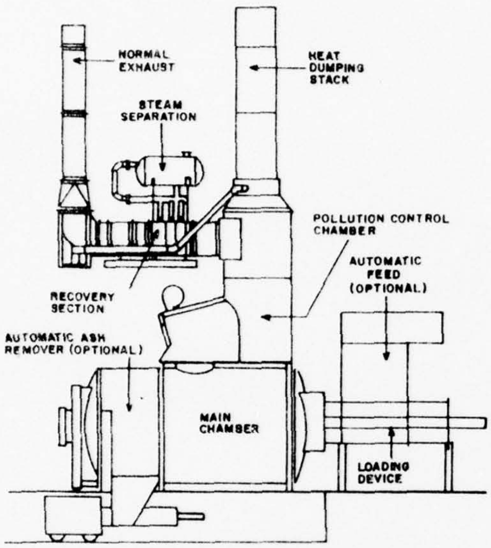

Figure 7. Stack bypass system on controlled-air incinerator.

period, is currently assumed to annualize up to 6.5 percent of equipment capital cost. This factor is approximately 50 percent greater than maintenance estimating factors for pulverized-coal-burning power plants given in AR 420-8.[32] Other estimated repair costs include replacement of the primary chamber every 7 to 10 years, and secondary chamber replacement occurring every 8 to 12 years. Preventive maintenance (e.g., lubrication, small parts and equipment repair or replacement) is normally assumed to be carried out regularly by available plant labor.

Instrumentation and Controls. Instrumentation includes equipment to indicate and/or record physical conditions which are relayed to operating personnel as signals. Controls are devices which change operating conditions, and may be either manual or automatic. Currently, manufactured controlled-air, heat-recovery incinerator systems have a minimum of instrumentation and controls. These include (1) pushbutton start of automatic charging cycling, (2) temperature indicator and controller for primary and secondary chambers, (3) primary chamber temperature-set quench for overheating protection, (4) fire control system for ram-feed hopper, (5) air modulation controls, (6) on-off primary burner control, (7) modulating secondary burner control, and (8) Factory Mutual or Factory Insurance Association burner controls and safeguards. Additional instrumentation and controls (e.g., for separate boiler operation) can usually be provided upon request at additional cost.

Functional Life. There are no operational data to support the assumption that the controlled-air, heat-recovery incineration system will have a functional life customarily associated with permanent and semi-permanent facilities without major equipment replacement. Current indications point to primary chamber replacement after 7 to 10 years and secondary chamber replacement after approximately 12 years, with insignificant terminal value of the replaced equipment.

Unit Operations

Process Flow. Figure 8 illustrates the general process flow of a controlled-air, heat-recovery incineration system. Essential operations include load weighing and delivery, handling and separation of bypass wastes, storage, feeding, incineration and heat exchange. Size reduction of separated bulky combustible wastes is optional. Addition of air pollution control equipment is shown as optional, because it depends on the performance characteristics of the chosen incinerator and the prevailing pollution regulations at the location of implementation.

Waste Weighing. Accurate plant performance evaluation requires that weight records be maintained for all material passing to and from the plant. Existing scales can be used for this task; however, if no scales are available, the recommended weigh station consists of a standard platform-type truck scale on an excavated concrete foundation. The weigh system may be fully automated by applying an automatic ticket system and/or equipment to remotely record and print vehicle data, date and time, and loaded weight in the incinerator plant control room.

Waste Delivery. Waste deliveries may be made by using plant drive-through or back-in systems, depending on the land area available and local traffic patterns. The drive-through system adds to plant cost by requiring greater building area, but is advantageous because it keeps all operations within one enclosure. The back-in system is efficient, generally requiring less building area, but does require a turning area in front of the

[32] AR 420-8, *Unconstrained Requirements Reports* (Department of the Army, 1976).

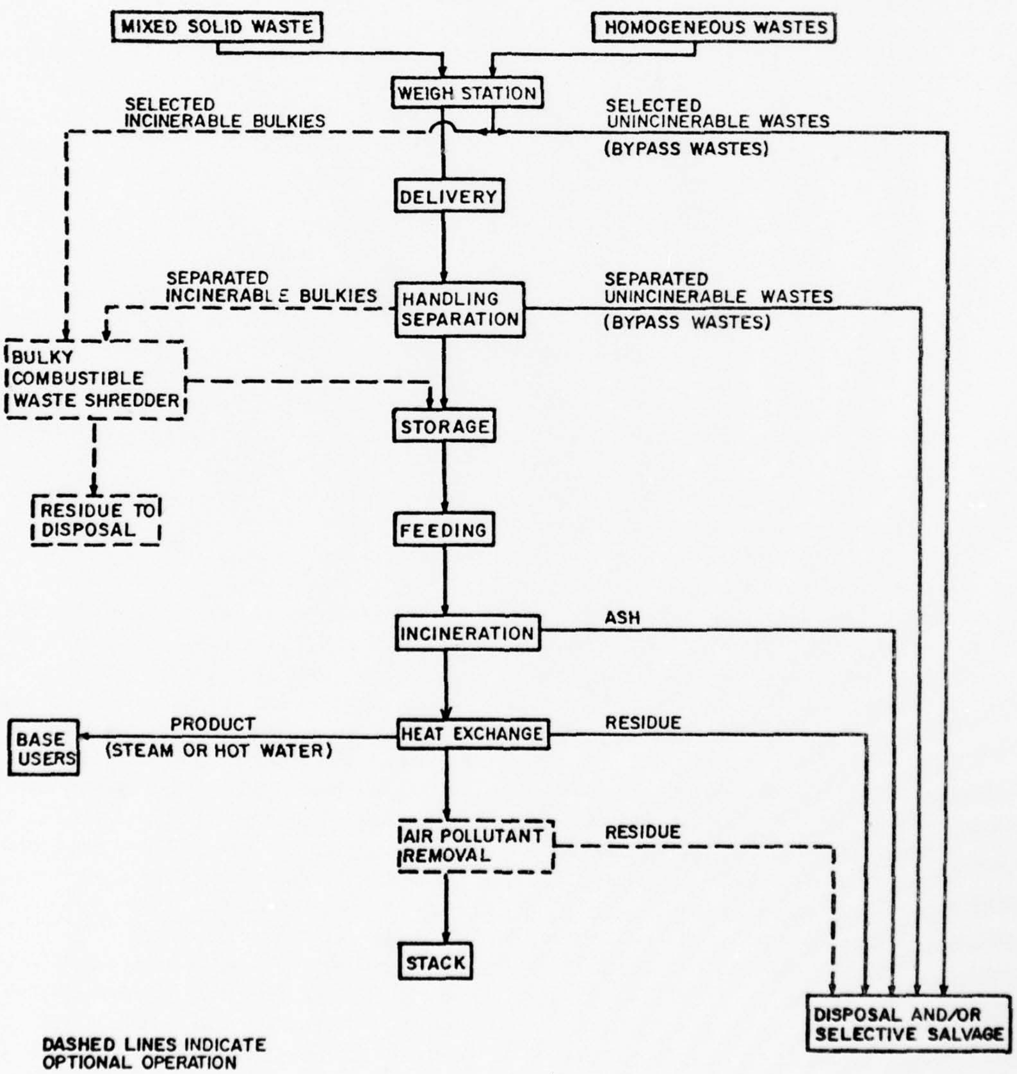

Figure 8. General process flow of a controlled-air, heat-recovery system.

building. The back-in system of waste delivery is recommended largely for economic reasons.

Delivery door clearances should be at least 24 feet (730 cm), with a minimum width of 20 feet (608 cm). Pure bypass wastes such as white goods and concrete should be delivered to ultimate disposal after weighing and not delivered to the incinerator plant. If a bulky combustible wastes shredder is used, such materials may be weighed and delivered directly to stockpile.

The delivery area should be completely visible from the plant control room. Exterior lighted indicators may be used to signal the drivers about which delivery entrance to use.

Handling and Separation. The tipping floor, front-end loader system of in-plant handling is recommended over the pit-and-crane system. The floor-loader system can handle up to 650 tons/day (592 mt/day); however, the pit-and-crane system operates on a first in/last out basis, is costly, and often causes difficulty in maintaining desired levels of waste separation, plant sanitation, and odor control. Moreover, crane outage, however brief, will stop all waste processing until repairs are made, unless a redundant crane is installed at added cost. If the front-end loader breaks down, similar equipment for temporary replacement is usually available either on the installation or from local commercial construction equipment rental companies. The recommended front-end loader uses propane fuel, has filled tires to prevent blowout, and is equipped with an enclosed, total-visibility, air-conditioned cab having appropriate communication and safety devices. Bucket capacity should be at least 1 cubic yard (0.76 m^3). The front-end loader operator is responsible for separating all bypass wastes from the incinerator feed stream, managing stored waste, and depositing waste in the incinerator ram feeder as required.

Storage. Depending on waste nature and condition, variability of daily waste generation, plant operating schedule, and availability of alternative means of waste processing or disposal, an in-plant storage area can provide up to 3 days' capacity. Adequate storage area is usually provided by sizing the tipping floor to accommodate a waste pile from 8 to 10 feet (244 to 305 cm) high; sufficient room should be allowed for working, equipment clearance, and safe personnel evacuation routes in case of fire.

Feeding. The recommended feeding method is by front-end loader; waste is fed directly from the tipping floor or storage area to the incinerator ram feeder. Some designs have automated this operation by installing a pit and elevating conveyors and automatic dump stations above each ram feeder. Such measures are discouraged, however, because they add to plant capital and O&M cost, while reducing overall system reliability. A working wall should be provided on two sides of the ram feeder, with the ram feeder top gate (compacting door) functioning as the rear working wall when it is in the open position. The ram feeder and other equipment should be installed so that waste need not be lifted to be deposited into it. Feeding system design should include adequate fire safety equipment, fire extinguishing devices, and high-volume room ventilation in case the ram feeder withdraws burning or smoldering materials on its back cycle.

Product. The controlled-air system may be used to produce hot water or steam. Hot water applications can include space heating and/or cooling, and feedwater preheat for a larger heating or power plant. Steam production capability generally does not exceed 250 psig (1991 kPa) saturated. There is no evidence that the controlled-air system has ever been used for electrical power production. Most applications produce saturated steam for either direct heating/cooling of nearby buildings (i.e., hospital, large office building) or feeding into an existing main header to join steam generated by an existing heating or power plant. Steam quality and pressure depend on the nature of user demand. Location near an existing heating or power plant allows use of existing facilities and equipment for product distribution and feedwater preparation, thus reducing plant investment and operations and maintenance costs. Generally, the controlled-air system will produce between 2.2 and 2.6 lb (1.0 and 1.2 kg) of steam (150 psig [1034 kPa] saturated) per pound of solid waste, resulting in proportional clean fuel savings.

Disposition of Ash, Residue, and Bypass Wastes. These materials, which can comprise up to 50 percent by weight of the installation waste stream, are a disposal requirement even when a heat-recovery incineration system is implemented. All such materials should be weighed so that overall plant processing efficiency can be calculated accurately. Existing waste-hauling vehicles can be used to move these materials to ultimate disposal or salvage stockpile. Covered trucks are usually required to haul ash and residue to reduce their windblown disperson during transport.

Pollution Control. Data to date indicate that air pollutant emissions from the controlled-air incinerator

are within most legal limits, which allows most plant designs to exclude air pollution control apparatus. Nevertheless, plant layout should provide for future addition of such apparatus in case emission laws change or equipment performs less satisfactorily than expected.

Ash quench water will require treatment for low pH and heavy metals removal; it should generally not be discharged directly into a sanitary sewer system. Wastewater from tipping floor washing may also require treatment before discharge.

Incinerator ash and residue are never completely sterile or inert; they can contain an appreciable quantity of incompletely burned organic materials (Figure 9). Ultimate disposal of these materials should be undertaken with the same general environmental precautions as disposal of as-collected waste materials.

The nuisance factor of incinerator plants is not low. Noise, vibration, odor, windblown material, increased traffic levels, attraction of pests and rodents, plume visibility, and general visual aesthetics are factors which must be considered both in site selection and plant design. A solid public relations campaign beginning in the planning stages of the heat-recovery incinerator plant will permit public input into the decision-making process and will alleviate potential misunderstanding of impacts that the plant might have on the environment.

Waste Preprocessing. Extensive pretreatment of waste before burning in the controlled-air incinerator is generally discouraged, because it adds substantially to plant capital and operations and maintenance costs, while subtracting from overall plant safety and reliability. An aggressive source separation program may enhance incinerator performance, while providing some revenue to the installation if glass, metals, and other potentially salvageable waste materials are generated in marketable quantities and condition. Bulky wood wastes too large to be fed to the incinerator can be processed in a special low-horsepower "pallet crusher" type shredder (Figure 10). Generally, shredding can be done once a week to process stockpiled bulkies; the shredded material can be discharged directly to the plant tipping floor. This type of shredder, which can be operated safely by one person, can break down bulky wood materials to a top size of about 18 in (549 cm).

General Plant Considerations

Location. Major factors governing the general location of a heat-recovery incinerator plant include land availability, existing and planned installation land-use patterns, haul distances, and availability of supporting facilities (i.e., steam distribution, power, etc.). Locating a plant in residential and other comparatively densely populated installation areas is discouraged. Implementation costs will be reduced by selecting a

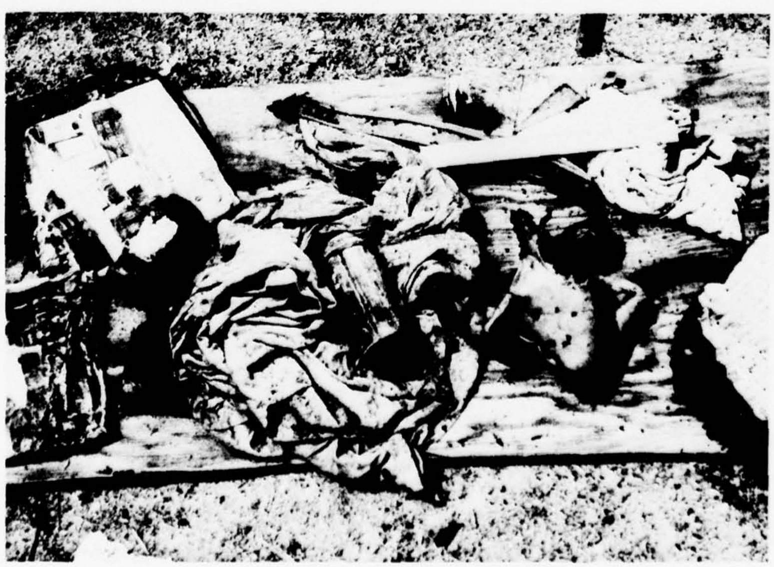

Figure 9. Charred materials.

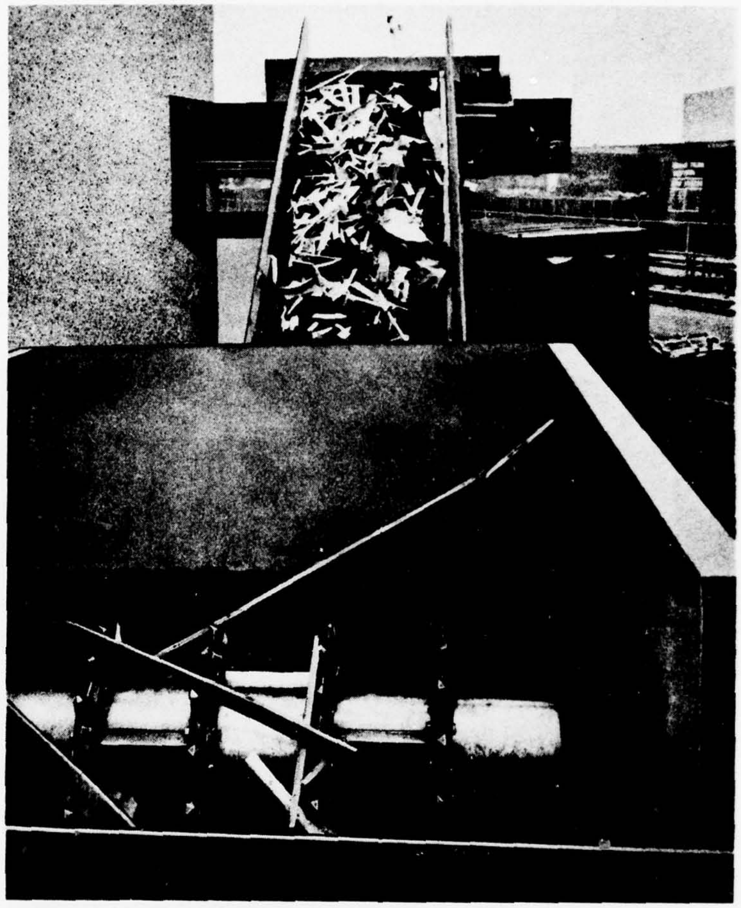

Figure 10. Pallet crusher.
(Reprinted by permission of Blower Application Company, manufacturer of the shredder depicted.)

location near existing utilities service and product user(s). Time spent in moving waste from points of generation to the plant and in returning to the collection route is usually more important than haul distance. It is sometimes beneficial to locate the plant near garage and shop facilities for waste collection vehicles. In choosing a location for a heat-recovery incineration plant, consideration must be given to installation development, redevelopment, change in land use and waste generation patterns, and future mission change.

Site. Experience has demonstrated that site considerations are important in determining the economic viability of a package heat-recovery incinerator system; therefore, site selection must be made and implementation costs carefully worked out during the project development stage. Table 4 lists general site selection factors that should be considered. A controlled-air, heat-recovery incinerator plant will require between 1.5 and 3 acres (0.6 and 1.2 hectares) of land, including exterior landscaped perimeter, depending on the amount of tipping floor area and the number of incinerators required.

Building. The recommended structure for having a controlled-air incinerator system is a steel-clad, pre-engineered building on a poured concrete foundation. Sufficient room should be provided for centralized control office, lockers and lavatory, meeting room,

Table 4
General Site Selection Factors for Heat-Recovery Incinerators

Factor	Design Criteria	Comment
Accessibility	Incinerator should be near source of waste and near roads for trucks.	
Waste Storage		Wind direction and distance to other buildings affect complaints about odors.
Steam Plume		Locate away from areas which may be affected by dispersion.
Soil Conditions		Affect foundations and drainage.
Grades	Employ two levels where possible to facilitate charging and ash removal without hoisting and improve drainage of storm water and sewage.	
Storage Facilities	Required for waste and ash containers.	
Electric Service	Required for motors, lights, and controls.	
Plumbing Service	Hot water required for washing ash containers; storm and sanitary sewers required.	
Climate		Affects type of enclosure.
Permanency		Consider possibility of moving incinerator for use at another installation.
Product	Distribution to user(s) nearby.	

storage of spare parts and maintenance equipment, waste delivery, waste handling, waste storage, dock for bypass wastes, dock for ash removal, and access for furnace and boiler removal and replacement. A bulky wastes shredder, if selected, may be located outside the building unless climatic conditions warrant enclosing it. Major equipment requires special foundation support. Delivery and main maintenance doors should have a minimal vertical clearance of 24 ft (732 cm) and a minimum width of 20 ft (610 cm). Existing buildings such as warehouses can be considered for conversion to an incinerator plant.

Layout. Figure 11 is an example plan view of a controlled-air, heat-recovery incinerator plant for an installation generating approximately 35 tons/day (32 mt/day) (5 days/week basis) of solid waste. The plant includes three parallel incinerator-boiler lines. The secondary incinerator chambers and boilers are elevated to conserve building area requirements. Space has been provided for future addition of air pollution control equipment, a fourth incinerator-boiler line, and a bulky waste shredder. Sufficient access has been allowed for removal of major equipment. The plant uses a back-in delivery mode with a tipping floor operation. No lifts are required to feed the incinerator ram feeders. Ash is removed from the rear of the building to minimize interference with delivery traffic. Entire plant operation is visible from the control room. The control and locker-lavatory rooms are accessible from the exterior of the plant. An extra room provided for employee meetings and/or meals has its main orientation away from the waste delivery and handling areas toward the outside.

Exterior. Judicious design and exterior landscaping can emphasize the building's positive aspects. When possible, trees and shrubs should be planted around the site perimeter to provide an attractive overall appearance. Good landscaping should be complemented by an

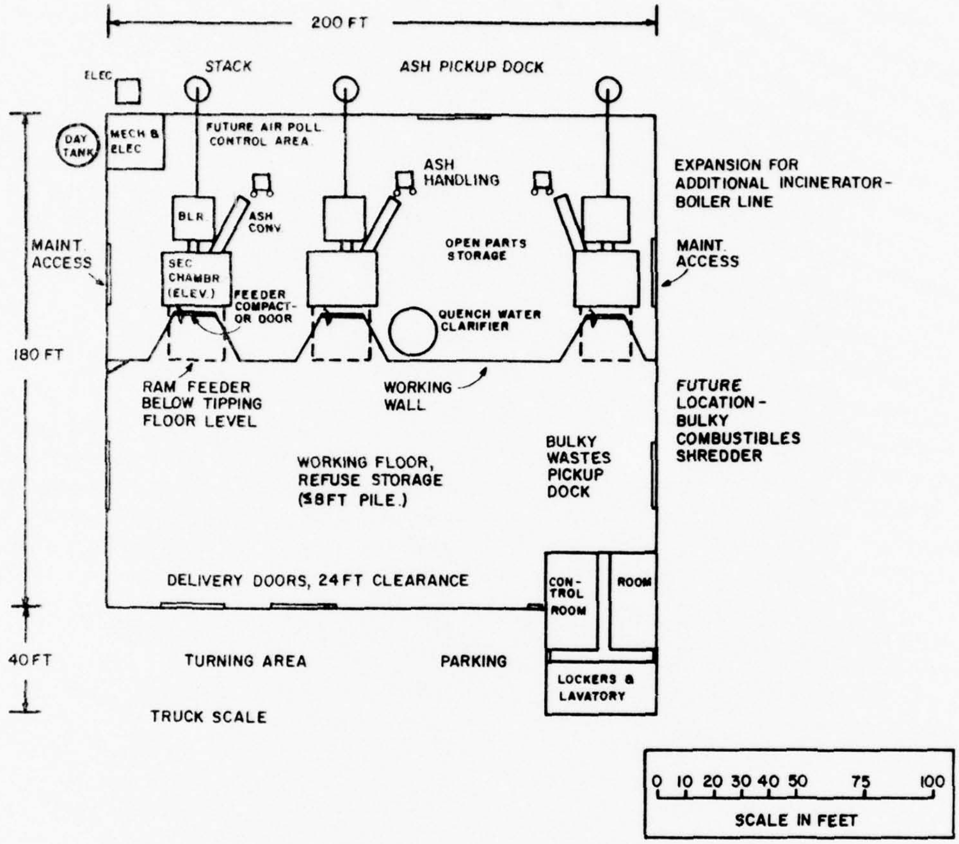

Figure 11. Example layout of a controlled-air, heat-recovery incinerator plant.

effective housekeeping program to minimize external litter. Fencing and yard lights should be provided, and the entrance(s) to the plant site should be secured during off hours.

Sanitation. An effective plant sanitation program includes regular cleaning of the tipping floor and handling equipment. Cleaning media may be supplemented with deodorants, insecticides, and detergents. Measures should be taken to minimize the presence of pests and rodents in and near the plant. Plant operation should include a regular program of removing litter from the grounds. Plant employees should be instructed in relevant aspects of plant sanitation and personal hygiene.

Employee Facilities and Safety. Plant design should include adequate facilities for personnel hygiene, meals, and meetings for working personnel. An ongoing program of safety inspection and training should be integrated into plant operation. Minimum requirements for ventilation and illumination should be met or exceeded. General safety equipment such as first aid kits, fire extinguishers, fire hose (wall nipples or hydrants), intercom, handlights, and equipment-related devices should be furnished. Employee safety equipment (hard hats, masks, goggles, protective clothing, safety shoes, fire blankets, cots, and stretchers) should be provided.

Records. Table 5 is a general list of records kept in an incinerator plant. Prevailing laws should be consulted to determine what records should be maintained for reporting purposes.

Technical Considerations in Project Development

Information Required for Project Development

Waste Characterization. Accurate waste characterization is a fundamental requirement for sound project development. Information required includes the daily

Table 5
Heat-Recovery Incinerator Plant Records

Nature	Type
Operational	Scaled drawing
	Safety procedures
	Equipment manuals
	Catalog
	Spare parts list
	Work task schedule
	Formal drawings
Performance	Residue characteristics
	Volume reduction
	Mass reduction
	Residue mass
	Bypass wastes mass
	Mass processed
	Costs per ton
	Supplies consumed
	Materials consumed
	Stack Opacity emissions
	Plant efficiency waste to product
	Delivered and removed weights
Furnace	Temperature data
	Hours of operation
	Total and excess air
	Gas temperatures in stack
Heat Exchanger	Production output
	Efficiency
	Blowdown
	Sootblowing schedule
Utilities	All
Other	Accidents
	Suggestions

waste mass and volume generation rates (usually expressed as tons/day, 5 days/week basis); waste condition, size, and constituency; and an assessment of how such data may change in the future at the installation. The waste survey must encompass both heterogeneous and homogeneous waste streams.

Waste Survey. The waste survey should be conducted for no less than 25 continuous data days. Mass, volume, condition, size, and (to a certain extent) constituency can be recorded at the weigh survey point. The ideal location for the waste survey is between collection of the last container and disposal. Existing scales can be used to obtain weights, provided that they have been calibrated recently and are accurate to ±2.5 percent. Portable truck scales are also available for purchase (≤ \$1000/unit) or lease (\$250/unit-month) for this purpose. Volume should be noted by visually observing the fullness of a container or collection vehicle of known capacity.

A final Data Report should include at least three sections: daily raw data, daily summary data, and comprehensive survey period summary data. Tables 6, 7, and 8 are examples of a daily work sheet, a daily summary sheet, and a survey summary, respectively. Each daily data sheet contains directly measured or observed volume and mass information, as well as size and condition data according to the classifications shown in Tables 9 and 10, respectively.

The time of year in which to conduct the waste survey should be selected in consultation with installation personnel experienced in waste disposal operations. A period representative of normal installation activity should be chosen. The daily summary report should note and explain any waste generation rates thought to be unusually high (e.g., a day following a holiday, weekend, or major equipment outage).

Waste Energy Content. Daily mass generation rate data are used to compute the amount of energy available from the waste on a daily basis. Unless the waste is highly unusual, it may be assumed to have an as-fired heating value ranging between 4000 Btu/lb (9.3 mJ/kg) and 5500 Btu/lb (11.9 mJ/kg), generally increasing with better waste condition. The daily waste energy content, D, is estimated, using Eq 6 in lieu of directly measured field data:

$$\frac{\text{Average tons}}{\text{day}} \times C\,\frac{\text{MBtu}}{\text{ton}} = D\,\frac{\text{MBtu}}{\text{day}} \qquad \text{[Eq 6]}$$

Actual values for C are 11.0 (Condition 1 waste), 10.0 (Condition 2), 8.8 (Condition 3), and 7.0 (Condition 4). For fractional average conditions (Table 8), linear interpolation may be used to obtain values of C. Using intensive field and laboratory analyses, the waste heating value in the example study summarized in Table 8 was found to be 5523 Btu/lb (12.8 mJ/kg). For this waste stream, the daily waste energy value was computed to be:

$$35.05\,\frac{\text{tons}}{\text{day}} \times 2000\,\frac{\text{lb}}{\text{ton}} \times 5523\,\frac{\text{Btu}}{\text{lb}} =$$

$$387{,}162{,}300\,\frac{\text{Btu}}{\text{day}}\ (408.1\ \text{gJ/day}) \qquad \text{[Eq 7]}$$

Table 6
Example Daily Waste Survey Work Sheet

Date: 4 Oct 77

Vehicle Identification	Empty Wt. (lb)	Loaded Wt. (lb)	Load Wt. (lb)	Empty Vol. (cu yd)	Fraction Full	Waste Vol. (cu yd)	Density (lb) (per cu yd)	Condition Code	Size Code	Constituency	Comments
117692	12500	18700	6200	37.0	0.9	33.3	186	2	4	Mixed	
124585	13000	20300	7300	40.5	0.9	36.5	200	2	3	Mixed	
Stake	8000	9900	1900	10.0	0.5	5.0	380	2	1	Mixed	Lots of metal pipe
4647	15600	23400	7800	24.4	1.0	24.4	320	4	5	Mixed	Wet slop
117694	12500	19300	6800	37.0	1.0	37.0	184	2	4	Mixed	
117692	12500	18500	6000	37.0	0.8	29.6	203	3	4	Mixed	
Stake	8000	10200	2200	10.0	1.0	10.0	220	2	4	Mixed	
124585	13000	20800	7800	40.5	0.9	36.5	214	2	4	Mixed	
117694	12500	19100	6600	37.0	0.8	29.6	223	3	5	Mixed	
4647	15600	22700	7100	24.4	0.9	22.0	323	1	1	Mixed	Lots of shop waste
117692	12500	19000	6500	37.0	0.9	33.3	195	2	4	Mixed	
Pickup	5000	5800	800	6.0	1.0	6.0	133	2	4	Mixed	
Total		67,000 (33.5 tons)				303.2	2781	31	43		
Average		5583 (2.8 tons/load)				25.3	232	2.58	3.58		
Standard Deviation		2466 (1.2 tons)				12.0	71.3	1.31	1.31		

(Metric Conversion Factors: 1 lb = 0.45 kg; 1 cu yd O 0.76 m^3; 1 lb/cu yd = 1.69 kg/m^3; 1 t = 0.9 mt.)

Table 7
Example Daily Waste Survey Summary Sheet

Date: 4 Oct 77
Number of Hauls: 12

	Tonnage	Cubic Yardage	Density	Size	Condition
Total	33.5	303.2	NA	NA	NA
Average	2.8	25.3	232	3.58	2.58
Standard Deviation	1.2	12.0	71.3	1.31	1.31
Maximum	3.0	37.0	380	5	4
Minimum	0.4	5.0	133	1	1

(Metric Conversion Factors: 1 t = 0.91 mt; 1 cu yd = 0.76 m^3, 1 lb/cu yd = 1.69 kg/m^3.)

It is convenient to state this as 387.2 MBtu/day (408.1 gJ/day). Had field and laboratory analysis not been carried out on this waste, a C factor of 11.0 would have been assumed based on waste condition, giving:

$$35.05 \times 11.0 = 385.6 \frac{\text{MBtu}}{\text{day}} (406.4 \text{ gJ/day}) \qquad \text{[Eq 8]}$$

If homogeneous wastes are recorded separately from the heterogeneous mixed wastes during the weigh survey, their daily waste energy values may be added to the value computed for the mixed waste stream.

Ash and Residue Content. Daily mass generation rate data are used to compute the daily quantity of ash and residue which must be removed from the heat-recovery plant and disposed of. Generally, an ash and residue content of 20 percent by weight can be assumed. For design purposes and economic analyses, the ash and residue mass is increased by 25 percent. For example data in Table 8, the estimated ash and residue quantity is:

$$30.05 \frac{\text{tons}}{\text{day}} \times 0.20 \times 1.25 = 7.5 \frac{\text{tons}}{\text{day}} (6.8 \frac{\text{mt}}{\text{day}}) \qquad \text{[Eq 9]}$$

Table 8
Example Waste Survey Grand Summary Sheet

Date: 7 Nov 77
Survey Period From: 3 Oct 77
To: 4 Nov 77 (No. weekends)
Number of Data Days: 25
Number of Hauls: 12

	Tons	Cubic Yards	Density	Size	Condition
Total	876.3	10384.6	NA	NA	NA
Average/Day	35.05	415.4	169	3.6	1.1
Standard Deviation	4.2	94.3	NA	1.2	0.7
Maximum	41	599.5	NA	5	4
Minimum	26	303.2	NA	1	1

(Metric Conversion Factors: 1 t = 0.91 mt; 1 cu yd = 0.76 m^3; 1 lb/cu yd = 1.69 kg/m^3.)

Table 9
General Size Grades of Mixed Solid Waste

Grade	Description
1	Wide size range of materials. Substantial bulkies (pallets, skids, cartons) present. Numerous small materials (paper stock, etc.). Bulky combustibles occupy 30 percent or greater surface areas of the aggregate waste stream. Few materials less than 3 ft (.9 m) maximum length.
2	Material size range smaller. Bulky combustible is substantial minority, occupying less than 25 percent of waste surface area. Few bulky incombultibles. Most materials less than 3 ft (.9 m) maximum length.
3	Limited material size range. Few bulky materials, which are irregularly generated. Most materials less than 3 ft (.9 m) maximum length.
4	Small material size range. Negligible amount of bulky materials. Bulky combustibles could easily be sorted from bulky incombustibles. Most materials less than 3 ft (.9 m) maximum length.
5	Small amount of large materials (nearly all elements in the waste would individually fit in the trunk of a car with ease).

Table 10
General Condition Grades of Mixed Solid Waste

Grade	Description
1	Marked near-homogeneity of waste stream. Imperfect mixture with clean, uncontaminated constituents. Salvageable materials easily removed in market-ready condition. Constituency is obvious. Waste rather dry.
2	Moderate mixture of mixed solid waste. Few "pockets" of clean, market-ready materials. Constituency is not obvious. Substantial contamination of all constituents (soiled, wet).
3	Highly mixed mixed solid waste with no apparent clean, market-ready materials. Great diversity of constituency. High degree of contamination of constituents. Numerous pockets of wet slop.
4	Highly mixed and soiled, contaminated. Greater than 75 percent is diverse wet slop of visually indeterminate constituency.

Incombustible bypass wastes identified during the waste survey do not enter this calculation, but their mass and volume generation rates must be retained for assessments of ultimate disposal requirements.

Bulk Reduction. The amount of reduction for waste going to ultimate disposal, such as to a landfill, is estimated in terms of volume and mass. Mass reduction can be estimated using Eq 9, where 30.05 - 7.5 = 22.6 fewer tons/day (20.6 mt/day) will pass to ultimate disposal, excluding separately identified bypass wastes. This is equivalent to a mass reduction of 75 percent. Cubic yardage data taken during the waste survey are used to estimate volume or bulk reduction, employing an estimating factor of 0.20. Hence, for example data in Table 8 a bulk reduction is estimated, which excludes the volume of bypass wastes that is added to the daily disposal requirement:

$$0.20 \times 415.4 \frac{\text{cubic yards}}{\text{day}} = 83.1 \frac{\text{cubic yards}}{\text{day}} (63.2 \frac{m^3}{\text{day}}) \quad \text{[Eq 10]}$$

The above estimating factor of 0.20 is based on an expected actual bulk reduction of 84 percent and a design factor of 25 percent.

Product. The amount of product that can be produced daily with available waste energy depends on plant operating schedule, system waste-to-product conversion efficiency, product quality and enthalpy, and feedwater enthalpy. The controlled-air system is limited to production of hot water and up to 250 psig (1724 kPa) saturated steam. A conversion efficiency of 0.60 is used in product calculations. Eq 11 may be used to calculate the daily quantity of waste-derived steam.

$$\frac{\text{Btu}}{\text{day}} \times \frac{1 \text{ lb steam}}{(h_f - h_g)} \times 0.60 = \frac{\text{lb steam}}{\text{day}} \qquad \text{[Eq 11]}$$

A system based on data shown in Table 11 with 387.2 MBtu/day (408.1 gJ/day) will yield 201,588 lb/day of 125 psig saturated steam (vapor enthalpy [hf] = 1190.5 Btu/lb), assuming feedwater entering the system at 70°F (21°C) (hg = 38.05 Btu/lb [88.48 gJ/kg]). Steam and water enthalpies can be found in standard steam tables. The quantity of steam produced from auxiliary fuel is added to obtain total plant steam production.

Product Compatibility. Maximum benefit from a waste-to-energy conversion system can be obtained only if all the product is usable. Generally, since the quantity of waste product derived from a controlled-air, heat-recovery system is substantially less than total user demand, there are no excess production problems. Compatibility of the waste-derived product with historical demands will allow some freedom in selecting the best plant operating schedule through tradeoff between capital investment and labor requirements. In some cases, the compatibility of the product with existing demands may be questionable and require a detailed investigation. In-depth, tie-in analysis requires comparing hourly waste-derived product output with user-based curves indicating maximum demand growth (Figure 12), annual load duration (Figure 13) and average 24-hour loads (Figure 14). Waste-derived product should be estimated over 7 hours effective production for a one-shift operation, 15 hours for a two-shift operation, and 24 hours for a three-shift operation. Design quantities of waste-derived product should be used, based on a 25 percent allowance factor. For example an installation with 201,588 lb/day (91 439 kg/day) of waste-derived steam potentially available would find that 16,799 lb/hour (7620 kg/hr) would be producible during a two-shift operation on a design basis for this level of compatibility analysis:

$$\frac{\text{lb steam}}{\text{day}} \times 1.25 \times \frac{1 \text{ operating day}}{15 \text{ hours}} =$$

$$16{,}799 \frac{\text{lb}}{\text{hour}} \left(7620 \frac{\text{kg}}{\text{hr}}\right) \qquad \text{[Eq 12]}$$

Equipment. The number of controlled-air incinerators required is based on available daily waste energy, a 25 percent design factor, a furnace limit of 18 MBtu/hr (18.99 gJ/hr), and the number of operating shifts per day. A tabular method is used, as indicated in Table 11, to determine actual and design plant waste-energy input capacities as a function of the number of possible operating shifts per day. Table 11 was created using example data from Table 8 and Eq 7, where 387.2 MBtu/day (408.1 gJ/day) of available waste energy was calculated. Actual values are employed in economic analyses where credits are taken for offset conventional fuel costs. Design values are used in plant sizing. Once data of the type shown in Table 11 have been computed, the minimal number of incinerators required for the array of plant input capacities can be determined. This is done by dividing each plant capacity by 18 MBtu/hr (18.9 gJ/hr)—the waste energy capability of the largest controlled-air incinerator currently available (approximately 1 ton/hour [0.9 mt/hour]). Table 12 illustrates data generated from data in Table 11 in this manner. The parenthesized values in Table 12 indicate the number of incinerators required with no redundant capability. These values were obtained by adding 0.9 to the computed values, and then

Table 11
Determination of Plant Capacity

Condition	Basis Days/Week	MBtu/Day Available	MBtu/Plant Input Capacity for Variable Number of Operating Shifts (Effective Burn Hours) 1 (7)	2 (15)	3 (24)
Actual	5	387.2	55.2	25.8	16.1
Design	5	484.1	69.2	32.3	20.2
Actual	7	276.6	39.5	18.4	11.5
Design	7	345.8	49.4	23.1	14.4

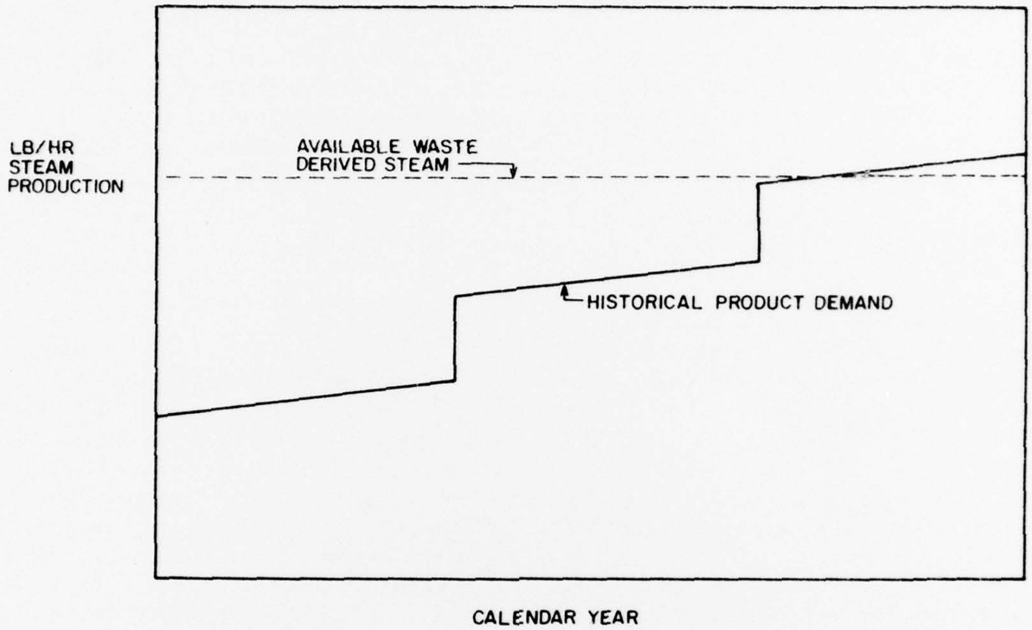

Figure 12. Maximum demand growth curve.

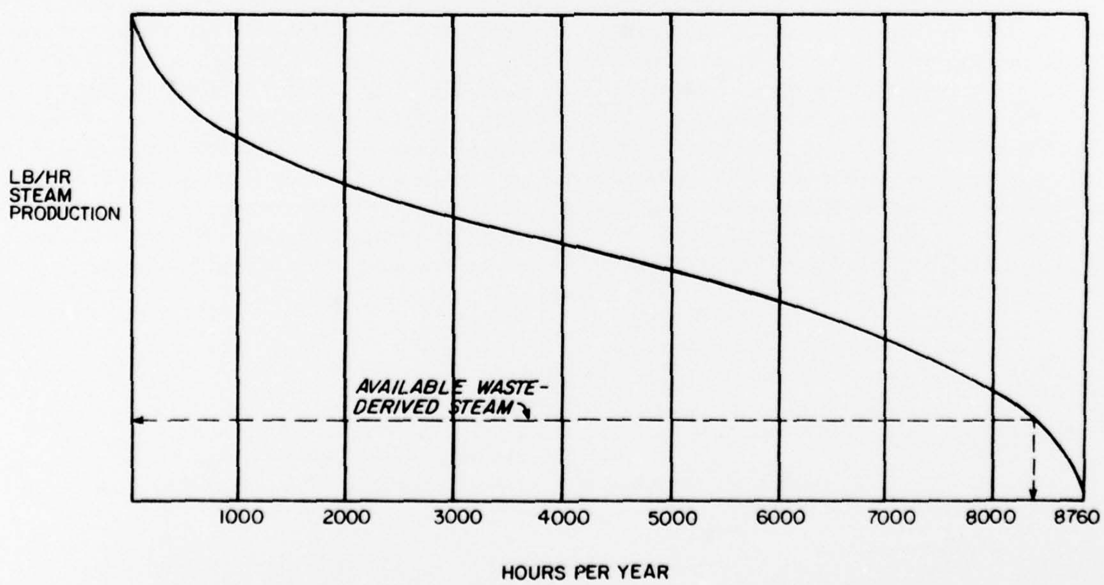

Figure 13. Annual load duration curve.

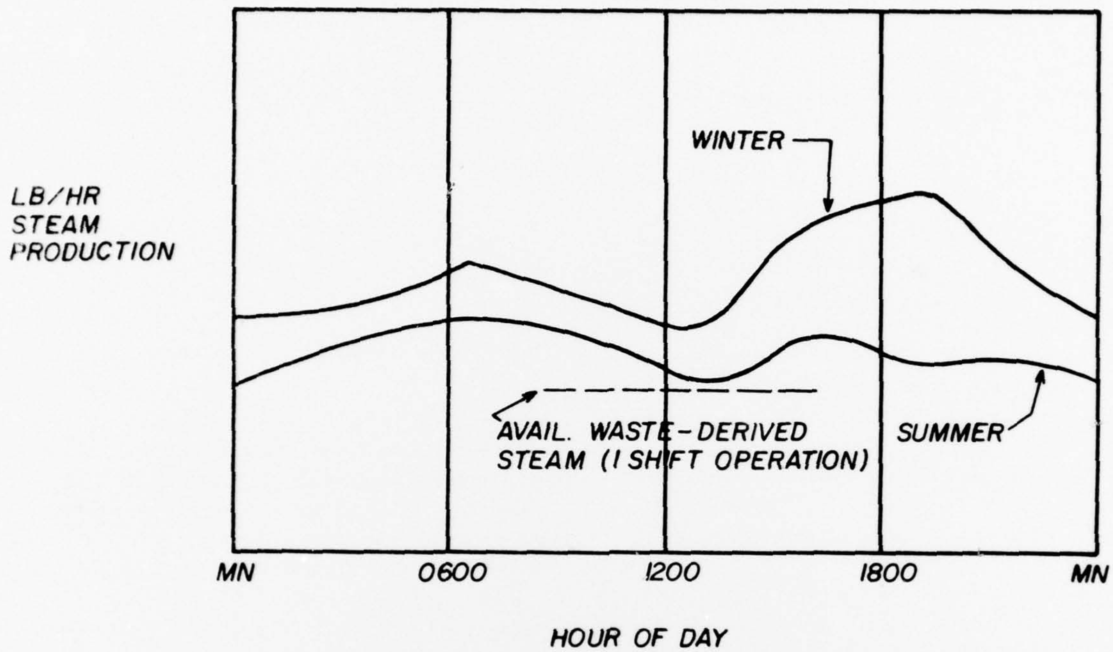

Figure 14. Average daily load curve.

truncating the sum. For example, $1.8 + 0.9 = 2.7 \rightarrow 2$; thus, two incinerators were found to be necessary for a two-shift 5-day operation design basis. A plant consisting of three incinerator-boiler lines, with two in parallel operation two shifts/day, 5 days/week, and the third available for alternate and peak load use, might be selected on the basis of data in Table 11. Because of loading frequency, it is inadvisable to plan on operating more than four incinerators in parallel.

Tipping Floor. The area required for delivery, handling and separation, and waste storage is a dominant factor in determining building size. For aesthetic, nuisance, safety, and health reasons, in-plant waste storage capacity should not exceed 3 days' average accumulation of waste. The waste storage area is calculated from average waste volume data determined from the waste survey. Planning for a maximum pile height will minimize the plant floor area requirement. Pile height does not generally exceed 10 ft (305 cm), and probably should not be greater than 8 ft for safety reasons. A design factor of 25 percent is used to determine the waste storage area. A two-step computation process is used to determine the storage area required. First, Eq 13 is used to obtain the required storage capacity in cubic feet:

Table 12
Incinerator Selection
MBtu/M Plant Capacity
(Minimal Number of Incinerators Required per Operating Shift)

Condition	Basis Days/Week	1	2	3
Actual	5	31 (4)	1.4 (2)	0.9 (1)
Design	5	3.8 (4)	1.8 (2)	1.1 (2)
Actual	7	2.2 (3)	1.0 (1)	0.6 (1)
Design	7	2.7 (3)	1.3 (2)	0.8 (1)

(Metric Conversion Factor: 1 MBtu = 1054 mJ.)

$$\frac{\text{Number of days}}{\text{capacity}} \times \frac{\text{cubic yards}}{\text{day}} \times \frac{\text{27 cubic feet}}{\text{cubic yard}} \times 1.25 = \frac{\text{cubic feet}}{\text{capacity}} \qquad \text{[Eq 13]}$$

For example, Table 8 data show that a generation rate of 415.4 cu yd/day (315.7 m^3/day) will lead to a 3-day waste storage requirement of 42,060 cu ft (31,966 m^3). The second step is computation of the pile side length, assuming zero relaxation, as required for various pile heights using Eqs 14 and 15:

$$\frac{\text{cubic feet}}{\text{capacity}} \times \frac{1 \text{ pile}}{\text{ft high}} = \frac{\text{square feet area}}{\text{capacity}} \qquad \text{[Eq 14]}$$

$$\left(\frac{\text{square feet area}}{\text{capacity}}\right)^{1/2} = \text{pile side in feet} \qquad \text{[Eq 15]}$$

Table 13 shows the results of applying Eqs 14 and 15 to data from Table 8 for a 3-day storage capacity. In this case, a floor area requirement of 5158 sq ft (377 m^2) might be selected to accommodate a pile 8 ft high. Pile storage requirement is the dominant factor used to determine tipping floor area. In developing a general plant layout, care must be taken to provide sufficient additional area for delivery, front-end-loader function, and safe personnel movement.

Table 13
Determination of Waste Storage Area

Pile Height (ft)	Floor Area (sq ft)	1 Pile Side (ft)
4	10515	103
5	8412	92
6	7010	84
7	6009	78
8	5158	73
9	4673	68
10	4206	65
11	3824	62
12	3505	59

(Metric Conversion Factor: 1 sq ft = 0.09 m^2; 1 ft = 0.3 m.)

General Building and Construction Requirements. Building dimensions are determined by several factors: tipping floor and waste storage area requirements; equipment dimensions; space for auxiliaries such as mechanical and electrical equipment, water treatment, and storage; control and other rooms; and maintenance access requirements. Addition of a bulky wastes shredder will not contribute to the required overall building area if it is located outside, but will add to the site's land requirement. Table 14 presents general size data for essential equipment in a controlled-air incinerator plant. These data and the layout concept shown in Figure 11 (p. 29) may be used in lieu of manufacturer-supplied information for project development purposes. Essential equipment requires special pad-type foundations. It is recommended that the primary chamber be elevated sufficiently so that underfire air ports can be safety reached for periodic cleanout. Ideally, a single structure houses the entire plant. Interior clearances are governed by delivery vehicle dimensions and, to a lesser degree, by equipment height. Whenever possible, a pre-engineered steel clad building on a poured concrete foundation should be used.

Labor. Historically, waste incineration has been a relatively labor-intensive operation. Even small plants may employ up to eight persons per shift. Required full-time labor includes a front-end-loader operator, an incinerator operator, at least one laborer, and often a general mechanic. Direct supervisory labor costs must be added, along with less direct costs incurred for increased administrative tasks and boiler attendance. Employee training in plant operation and safety will also be a significant recurring expense. Despite superior planning efforts and incentives, labor turnover in incinerator plants is high and causes problems in maintaining desired plant performance levels. It has been clearly demonstrated that operator talent and experience plays a role equal to or greater than that of modern equipment design in contributing to successful overall incinerator plant operation. This alone justifies every effort to maintain employee on-the-job longevity.

Plant Reliability and Disposal Backup. No operational data are available to conclusively identify the reliability of the controlled-air, heat-recovery incinerator system. Most project development efforts estimate 2 weeks scheduled and 2 weeks unscheduled plant outage over an operating year. A serviceability factor of 0.904 is used.

Table 14
Essential Equipment Dimensions for Use in Plant Sizing

Item	Length (ft)	Width (ft)	Height (ft)
Ram feed hopper (feed door elevated)	20	7	12
Primary combustion chamber	20	12	11
Secondary combustion chamber*	20	10	10
Boiler (15,000 lb/hour [6804 kg/hr] capacity**)	26	10	11
Ash quench and conveyor removal	20	8	6

Basis: Piggyback configuration, 1 ton/hour capacity
*Secondary chamber elevated above primary chamber.
**Boiler can be elevated above ash removal area at secondary chamber level.
(Metric Conversion Factor: 1 ft = 0.3 m.)

Several steps can be taken to increase the plant's theoretical serviceability. First, the plant operating schedule should be determined to allow time for extended operation either to compensate for downtime or to process peak loads. A two-shift, 5-day operation schedule will leave the third shift and weekends available for contingency.

Second, furnace selection should be such that full-load use is never planned. This "derating" procedure allows some flexibility in system throughput capability and is used partly because average military waste generally has a higher heat release than the average municipal-residential type waste for which the furnaces were designed. Referring to Tables 11 and 12, the processing flexibility for a two-shift, 5-day operation is $100 \times (36 - 32.3)/36 = 10$ percent on a design basis and $100 \times (36 - 25.8)/36 = 28$ percent on an actual basis.

Third, continuity in waste-processing capability is enhanced by adequately sizing the plant's waste storage capacity so that waste can continue to be delivered to the processing point, despite short-term process outage.

Finally, equipment redundancy can increase the overall reliability of waste processing. For example, referring to example data in Tables 11 and 12, three incinerator-boiler lines might be chosen instead of the minimally required two, with daily operations alternated among pairs. In this case, plant waste-processing flexibility would be $100 \times (54 - 32.3)/54 = 40.2$ percent design basis and $100 \times (54 - 25.8)/54 = 52.2$ percent actual basis.

Implementation of these steps will increase the waste processing system's overall reliability. Nevertheless, it is imprudent to plan for shutdown of ultimate disposal operations, such as landfill, when an incinerator plant is implemented. As noted earlier, ash, residue, and bypass wastes will remain a disposal requirement when the plant is in operation. Moreover, the combined scheduled and unscheduled plant outages will necessitate hauling waste directly to ultimate disposal for an estimated 4 weeks of every year.

Impact on Existing Waste Management System. Implementing an incineration plant will impact the entire spectrum of installation waste disposition operations. The collection and hauling of waste will be affected only slightly, and these impacts are limited largely to possible changes in pickup scheduling and/or vehicle routing, depending on the location of the incinerator plant. An incinerator plant will not shut down ultimate disposal operations, but may reduce associated labor and equipment costs. Implementing a heat-recovery incinerator system will usually require additional manpower and will create additional tasks for management personnel. The logistical aspects of integrating a heat-recovery system into all affected facets of installation operations affects project feasibility as much as does the availability of proper equipment.

Legal and Regulatory Constraints. All legal and regulatory constraints affecting implementation of a heat-recovery incinerator system must be evaluated during project development. Such constraints may pertain to pollutant emissions, performance standards, performance reporting, inspection schedules, building and equipment codes, and assessment of environmental impacts. Local, state, and Federal pollution control agencies may be consulted as sources of information.

Economic Considerations in Project Development

First Costs of Implementation

General. First costs are often termed as capital or investment costs, or the costs of ownership. Specific first costs discussed in this section are current as of the beginning of FY78 and should be used for project development purposes only if similar data cannot be obtained from manufacturers, vendors, or other reliable souces of information.

Information Sources. Numerous sources of information are readily available to the installation developing a controlled-air, heat-recovery incineration project. (See AR 415-17 for empirical cost estimating guidelines and factors.)[33] Numerous solid waste periodicals contain current information on all phases of solid waste management (Table 15). In addition, many organizations and associations can provide resource recovery information (Table 16). Published annually, the *Thomas Register* alphabetically lists names of major manufacturers in the United States cross-referenced by product.[34] Several annually published construction cost-estimating guides are available, including Richardson's *General Construction Estimating Standards,*[35]

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[33] *Empirical Cost Estimates for Military Construction and Cost Adjustment Factors*, AR 415-17 (Department of the Army, 9 August 1976).

[34] *Thomas Register* (Thomas Publishing Co. 1978).

[35] *General Construction Estimating Standards* (Richardson Engineering Services, 1977).

Table 15
Solid Waste Periodicals

NCCR Bulletin, 1211 Connecticut Ave., N. W., Washington, DC 20036

NSWMA Newsletter Technical Bulletin, National Solid Waste Management Association, 1730 Rhode Island Ave., NW, Suite 800, Washington, DC 20036

Recycling Today, Market News Publishing Corporation, 156 Fifth Ave., New York, NY 10010

Resource Recovery Magazine, Wakeman-Walworth, Inc., Box 1144, Darien, CT 06820

Reuse Recycle, Exchange Publishing Company, 750 Summer St., Sanford, CT 06901

Scrap Age, Three Sons Publishing Company, 6311 Gross Point, Niles, IL 60648

Solid Waste Report, Business Publishers, Inc., P.O. Box 1067, Blair Station, Silver Spring, MD 20910

Solid Waste Systems Magazine, Systems Publishing, Inc., 2333 West Third St., Los Angeles, CA 90057

Solid Waste Management Refuse Removal Journal, Communication Channels, Inc., 461 Eighth Ave., New York, NY 10001

Waste Age, Three Sons Publishing Co., 6311 Gross Point Road, Niles, IL 60648

Table 16
Organizations and Associations Providing Resource-Recovery Information

Aluminum Association, 750 Third Ave., New York, NY 10017, (212) 972-1800

American Consulting Engineers Council, 1155 15th St., NW, Washington, DC 20005, (202) 296-1780

American Iron and Steel Institute, Tinplate Producers, 150 East 42nd St., New York, NY 10017

American Paper Institute, 250 Madison Ave., New York, NY 10016, (212) 883-8014

American Public Works Association, 1313 East 60th St., Chicago, IL 60637, (312) 947-2520

American Society of Civil Engineers, 345 East 47th St., New York, NY 10017, (212) 752-6800, ext. 505

Bureau of Mines, U.S. Department of the Interior, Washington, DC 20240, (202) 634-1142

Council of State Governments, Ironworks Pike, Lexington, KY 40505, (606) 252-2291

Environmental Action, 1346 Connecticut Ave., NW, Washington, DC 20036, (202) 833-1845

National League of Cities/U.S. Conference of Mayors, Solid Waste Project, 1620 I St., NW, Washington, DC 20006, (202) 293-7177

Glass Container Manufacturer's Institute, 1800 K St., NW, Washington, DC 20006, (202) 872-1280

International City Management Association, 1140 Connecticut Ave., NW, Washington, DC 20036, (202) 293-2200

Institute of Scrap Iron and Steel, 1729 H St., NW, Washington, DC 20006, (202) 298-7660

League of Women Voters, 151 Hidden Road, Andover, MA 10810, (617) 475-8881

National Association of Counties, 1735 New York Ave., NW, Washington, DC 20036, (202) 785-9577

National Association of Recycling Industries, 330 Madison Ave., New York, NY 10017, (212) 867-7330

National Center for Resource Recovery, Director of Information, 1211 Connecticut Ave., NW, Washington, DC 20036, (202) 223-6154

National Solid Wastes Management Association, 1730 Rhode Island Ave., NW, Suite 800, Washington, DC 20036, (202) 659-4613

Office of Solid Waste Management Programs, Resource Recovery Division, U.S. Environmental Protection Agency, Washington, DC 20460, (202) 254-7840

Process Plant Construction Estimating Standards,[36] and *Means Cost Estimating Data.*[37]

Weigh Station. The installed cost of a platform-type truck scale on excavated concrete foundation, including an automatic weighing system and remote printout, ranges between \$20,000 and \$33,500, depending on site requirements, shipping distance, and type and capacity of scale selected.

Delivery. No equipment is necessary for most delivery systems, and other costs must be estimated locally. Concrete driveways and aprons, plus a turning area if a drive-through delivery mode is not selected, should be included in the delivery design cost estimates.

Handling and Separation. Front-end loaders are required, and often are included as separately funded items. Procurement cost ranges between \$9500 and \$16,000 per unit. The capital cost estimate should include replacement of front-end loaders after every 8 years of service.

Combustion Equipment. A single line consisting of ram feeder, piggyback controlled-air incinerator with a 1 ton/hr (0.9 mt/hr) nominal capacity, ash quench and conveyor, afterburner, fans, controls and instrumentation, and refractory-lined stack can range in cost between \$150,000 and \$285,000 at the site of manufacture. Installed cost depends on shipping weight, shipment distance, and required sitework. Simultaneous installation of multiple lines can reduce the installation cost by 5 to 10 percent.

Heat Exchanger. The installed cost of a package watertube boiler can be estimated at \$19.25/lb-hr designed steaming capacity. This cost includes controls, fans, a separator, a burner, and sootblowers, but excludes feedwater treatment. Use of firetube boilers is not recommended.

Feedwater Treatment. Existing feedwater treatment facilities should be used whenever possible to minimize first costs of the heat-recovery incinerator plant. In such cases, the cost of feedwater tie-in is estimated locally. New feedwater treatment facilities can range in installed cost between \$20,000 and \$65,000, depending on water properties and attendant treatment requirements.

[36] *Process Plant Construction Estimating Standards* (Richardson Engineering Services).

[37] *Means Cost Estimating Data* (R. S. Means Co., 1977).

Auxiliary Fuel. Provisions for auxiliary fuel include lines and, in many cases, a day tank. The cost of fuel lines must be estimated locally. An above-ground day tank and auxiliaries, insulated, heated, and having a 1000-gal (3785-liter) capacity (including valves, pumps, and gauges), ranges in cost between \$9000 and \$13,000.

Air Pollution Control. The installed cost of modular wet scrubbers for particulate emissions abatement can range between \$70,000 and \$210,000 per unit, including instrumentation and controls, auxiliary equipment, and clarification tank; these costs depend largely on gas flow rate and desired collection efficiency. Manufacturers and vendors of controlled-air incinerator systems usually can provide accurate installed cost estimates of air pollution control equipment.

Steam Distribution and Condensate Return. Costs of these items must be estimated locally. Cathodic protection should be included where appropriate.

Hot Water Applications. Costs of hot water distribution and return lines must be estimated locally. Cathodic protection should be provided where appropriate.

Preprocessing Equipment. The installed cost of a bulky waste shredder, including feed and discharge conveyors, ranges between \$40,000 and \$85,000, depending on capacity and site requirements.

Building. Building costs must be estimated locally with consideration given to site-specific factors such as soil geology and climate. In many regions, a pre-engineered, steel-clad structure on poured concrete slab foundation is suitable. Usual estimates for such a structure on a dollar per square foot basis are: general, \$22.00; plumbing, \$0.40; electrical and mechanical, \$1.44; heating, \$1.53; odor control ductwork and vents, \$0.30; and fire protection system, \$1.56. The total of \$27.23 per square foot excludes special equipment foundations, site preparation, exterior ramps and paving, special interior structural work, supporting facilities, and post-construction landscaping.

Site Preparation. Site preparation costs must be estimated locally. Such costs may include clearing, grading, excavation, backfill, and topsoil. Where appropriate, erosion control provisions should be included.

Supporting Facilities. These costs must be estimated locally. Consideration must be given to electrical substation and distribution lines, yard lighting and fencing,

telephone, intercom, water supply, sanitary and storm sewers, fuel lines and meters, fire alarm lines, demolition or modification of existing structures, vehicle parking, and drives. Included as supporting facilities are steam distribution and condensate return, feedwater treatment, and auxiliary fuel supply, as discussed in previous sections.

Expense Items. These costs must be estimated locally. Expense items include desks, file cabinets, clocks, waste containers, book cases, clothing lockers, laboratory equipment, washdown hoses, and other similar items, most of which are obtainable via the General Services Administration.

Resources on Hand. Use of resources on hand helps to minimize first costs. Such resources include platform or other suitable scales, front-end loaders, waste-hauling vehicles for ash removal, and expense items.

Startup and Field Alignment. Depending on system complexity, startup and field alignment costs can range between $10,000 and $50,000.

Operator Training. Ideally, training of operators, supervisors, and backup personnel should begin when the project is in the design stages and continue through the time that the system is on-line. Cost of training personnel must be obtained from the equipment supplier. Total personnel time required for training averages 1 month per person.

Compliance Tests. Compliance tests are required for, at a minimum, air pollutant emissions. The cost of emissions testing can range between $2500 and $5000. Local or state pollution control agencies can usually provide information about what types of compliance tests are necessary and a general estimate of their costs.

Acceptance Tests. Acceptance tests should be carried out, particularly in turnkey type contracts, to verify that overall system performance agrees with specifications. Generally, such tests should be carried out for a minimum of 1 week of normal plant operation when typical input material is burned. Costs of performance acceptance evaluation can range from $5000 to as much as $75,000 depending on plant complexity, operation schedule, and staffing requirements.

Environmental Impact Evaluations. A formal environmental impact assessment (EIA) or, in many cases, a formal environmental impact statement (EIS) will be required for a heat-recovery incinerator plant. These can be done either by contract or by installation personnel. Computerized systems are available to assist in the preparation of either the EIA or EIS.[38] Costs for final EIA preparation can range between $10,000 and $30,000, and costs for final EIS preparation can range between $30,000 and $100,000, if done by a contractor.

The Line Item Capital Cost. Capital cost estimates must include the costs of procurement, transportation, installation, startup, and shakedown. It is useful to distinguish between costs for equipment and costs for facility. Heat-recovery incineration equipment can require as much as 18 months of field debugging time, depending on the degree of innovation, complexity, and performance specifications. These and other costs associated with turnkey equipment readiness should be included with each line item of equipment. Normally, supporting facilities (e.g., utilities, building landscaping) do not require such adjustment.

Line Item Capital Cost Adjustments. The capital cost for a future project year must be estimated based on current data. These projections for project year cost must consider the changing value of money with time, time-related technological changes, and regional economic differences. The method for treating these phenomena is explained in AR 415-17.

There are four major steps in the capital cost projection. First, the project construction midpoint must be determined. If a project requires 1 year for construction, and construction begins on 1 October 1979 (FY80), the midpoint will be 1 April 1979 (FY80).

Second, each capital cost item must be adjusted for geographic economic differences (adjustment factors are presented in AR 415-17). The estimator must distinguish between site-specific cost quotes which require no geographic factor adjustment, and national average costs estimated from sources such as AR 415-17 which require geographic adjustment.

Third, allowance must be made for the changing value of money between the date of the estimate and the future construction midpoint by using the building cost index figures given in AR 415-17.

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[38] L. V. Urban, et al., *Computer-Aided Environmental Impact Analysis for Construction Activities*, Technical Report E-50/ADA008988 (CERL, March 1975).

Fourth, allowance must be made for cost growth resulting from technological change by adjusting the geographic- and time-adjusted cost, using a technological updating factor. AR 415-17 lists this factor as 1.18 for central heat and refrigeration plants.

Summing Capital Cost Adjustments. The line item capital costs for equipment and facility are summed after they have been adjusted as described in the preceding paragraph.

Three adjustments are made to the summed capital cost. First, 10 percent of the sum is added as contractor profit. Five percent of this new sum is then added for supervision and administration costs. This total represents the total funded portion of the project. Six percent of the funded portion is then added as the unfunded portion. The total represents the total project's funded and unfunded portions.

Recurring Costs of Implementation

General. Recurring costs of implementation are operation and maintenance costs which must be paid every year of the plant's functional life. This section provides general guidance for estimating the annual operation and maintenance costs of a controlled-air, heat-recovery incinerator plant. The last section of this chapter provides information on estimating the tangible benefits of implementation.

Information Sources. Sources of information mentioned earlier and listed in Tables 15 and 16 may be used. Moreover, it is recommended that personnel at operating controlled-air plants be contacted to obtain current information on operation and maintenance costs. Particular attention should be given to obtaining accurate cost estimates for auxiliary fuel, electrical power, labor, and maintenance and repair, since the overall economic effectiveness of a controlled-air, heat-recovery plant is very sensitive to these annual cost line items.

Auxiliary Fuel. The ignition and afterburner (auxiliary) fuel requirement is stated in terms of MBtu/MBtu design quantity waste to be processed. The following equation may be used:

$$\ln |T \times \text{MBtu waste/hour}| = \text{MBtu/hr fuel} \qquad \text{[Eq 15]}$$

Values of T for different auxiliary fuels are as follows: No. 6 (0.42), No. 2 (0.34), and natural gas (0.31).

For example, if a plant were designed to process 32.3 MBtu/hr (34.0 gJ/hr) of waste (Table 11) using No. 2 fuel oil as supplementary fuel, then the hourly clean fuel requirement would be:

$$\ln |0.34 \times 32.3| = 2.40 \text{ MBtu/hr } (2.5 \text{ gJ/hr}) \text{ fuel} \qquad \text{[Eq 16]}$$

The gallonage required is:

$$240 \frac{\text{MBtu}}{\text{hr}} \times 1{,}000{,}000 \times \frac{1 \text{ gal}}{139{,}000 \text{ Btu}}$$
$$= 17.27 \text{ gal/hr } (65 \text{ ℓ/hr})$$

To compute the annual cost, the yearly clean fuel gallonage can be determined from the hourly consumption.

Other Fuel. Fuel consumption of front-end loaders can normally be estimated by using 0.20 MBtu/hr (211 gJ/hr) of operation, which is approximately equivalent to 2 gal/hr (7 ℓ/hr) of liquid fuel.

Water. General plant water requirements may be estimated as 20 gpm (76 ℓ/min) with ash quench requiring 5 gpm/unit (19 ℓ/min) and wet scrubbers 60 gpm/unit (227 ℓ/min). Information about water consumption of other auxiliaries (e.g., furnace, quench) must be obtained from the equipment supplier. Boiler feedwater should be accounted for only if it is additive to what is used for current post heating system operations. The operation of most heat-recovery incinerator plants relies on existing feedwater systems and reduces feedwater treatment requirements at a tie-in plant.

Water Treatment. Existing facilities for water treatment (e.g., blowdown, scrubber, and ash quench liquor) are usually used at no cost increase. However, an estimated additional cost of \$0.10/ton (0.11/mt) of waste processed should be estimated for chemically treating ash quench liquor in the plant.

Electrical Power. A plant's general hourly electrical power consumption may be estimated at 15 kW, and daily waste processing power consumption at 30 kWh/ton (119 mJ/mt) of waste processed. An additional 18 kW per hour must be added for each scrubber used. The power equipment of a bulky wastes shredder will use approximately 35 kW per hour of operation.

Maintenance and Repair. Annual maintenance and repair costs may be estimated as 5.5 percent of the total current year installed equipment cost without adjustment by geographic, construction midpoint, and technological updating factors.

Sanitation. The annual cost of general plant housekeeping and sanitation can be estimated as \$0.15/ton (\$0.16/mt) of waste processed.

Pest and Rodent Control. The annual cost of pest and rodent control can be estimated as \$0.90/ton (\$0.81/mt) of waste processed.

Ash, Residue, and Bypass Waste Disposition. The annual cost of disposing of ash, residue, and bypass wastes should be estimated locally. These materials will be disposed of during 90.4 percent of the operating year. Because of unforeseen and scheduled plant outage, the total unprocessed waste stream will be disposed of during 9.6 percent of the operating year.

Labor. The total employee cost (salary, plus overhead, etc.) must be used to estimate the annual labor cost. The minimum labor requirement is one front-end loader operator, one incinerator-boiler operator, and one mechanic/laborer per shift. The cost of supervisory labor (e.g., a foreman) who may not be in constant attendance should be included, as well as the costs for plant management and administration (typically 1/12 person-year) and any additional labor required of property disposal personnel for bypass waste salvage.

Parts Inventory. Maintaining a complete inventory of replacement parts will help minimize plant downtime and maximize the benefits of operation. Annual costs of maintaining such an inventory can range between \$1000 and \$15,000. The cost must be determined in consultation with the equipment supplier.

Indirect or Hidden Costs. Other identifiable costs associated with implementing a heat-recovery incineration system include operation and maintenance of new cathodic protection systems for underground pipes, special boiler feedwater treatment, operation of a collection vehicle washrack, and possibly longer haul distances to the incinerator plant than to existing disposal points. These costs should be included in the total.

Repair by Replacement. Because of brief operational history, the functional life of a controlled-air, heat-recovery incinerator system is unknown. Current opinions indicate that the furnace must be replaced every 7 to 10 operating years and that the secondary chamber must be replaced after approximately 12 years. Because there is no precedent, no cost can be assigned to repair by replacement. The estimator should note that this and perhaps other cyclically appearing annual costs will occur.

Recurring Benefits of Implementation

General. Recurring benefits of implementation are usually fuel savings gained by producing steam or hot water from waste instead of fossil fuel combustion. Other offset or avoided costs may involve labor and waste disposal.

Fuel. Fuel savings are given in terms of how much currently used fuel would be consumed to produce the same amount of product (steam or hot water) produced by the heat-recovery incinerator plant. Actual, not design, quantities of the product must be used in this computation. The fuel-to-product efficiency of the existing system must be considered. For example, if a daily amount (Q_W) of 201,588 lb (91,439 kg) of 125 psig (861.9 kPa) waste-derived steam is to be produced and distributed to an existing system using No. 6 fuel oil (150,000 Btu/gal, °F [41.8 mJ/ℓ/°C]) with an overall efficiency (E) of 0.78, a 220°F (104°C) feedwater enthalpy (h_f) of 38.05 Btu/lb (88.5 kJ/kg) and a steam enthalpy (h_g) 1190.5 Btu/lb (2.8 mJ/kg), the fuel savings are:

$$\frac{Q_w}{E \times F \times \dfrac{1}{(h_g - h_f)}} = \frac{201{,}588}{0.78 \times 150{,}000 \times \dfrac{1}{1152.45}}$$

$$= 1986 \text{ gallons/day } (7517\ \ell/\text{day}) \qquad \text{[Eq 18]}$$

Labor. In some cases, the number of new personnel can be minimized by implementing a heat-recovery incinerator plant. For example, existing landfill equipment operators might be reassigned to operate front-end loaders. In some cases, existing heating plant labor can be used for periodic boiler attendance. The value of existing labor (salary plus overhead, etc.) saved by implementing the heat-recovery system, either through reassignment or elimination, is a tangible benefit.

Disposal. Like labor savings, disposal savings must be estimated locally. These savings can include landfill equipment operations and maintenance and reduced hauling costs. When estimating these savings, the estimator should remember the total waste stream must be disposed of at least 9.6 percent of the plant's operating year because of both unforeseen and scheduled outage.

Indirect and Hidden Benefits. Other avoided future annual costs resulting from heat-recovery incinerator plant implementation must be estimated locally, because they are very site-specific.

4 CONCLUSIONS

The controlled-air, heat-recovery solid waste incinerator has potential application at Army fixed facilities and installations generating up to 60 tons/day solid waste. Guidance provided in Chapter 3 of this report may be used with acceptable confidence to support development of projects applying the controlled-air, heat-recovery system.

There is a degree of uncertainty and risk regarding the performance of the controlled-air system and its life cycle costs and benefits. This uncertainty is due to its brief history of operation, insufficient instrumentation and recordkeeping at operating facilities, and industry's tendencies to market equipment before completing investigative and developmental work.

Risks associated with implementing the controlled-air system involve potentially changing waste characteristics, unknown reliability of major equipment, possible changes in demand for product steam or hot water, and potential limitations on disposal of ash and residue.

Careful monitoring of planned and operating facilities is required to gain further empirical performance and economic data for subsequent use of controlled-air systems in project development.

5 RECOMMENDATIONS

It is recommended that application guidance provided in Chapter 3 be issued as an Engineer Technical Letter. The information should be used to support development of projects applying the controlled-air, heat-recovery solid waste incinerator at Army fixed facilities and installations, and incorporated into future revisions of TM 5-814-5, *Incinerators.*

It is also recommended that Army use of the controlled-air system be accompanied by a thorough instrumentation and performance monitoring effort geared toward collecting further empirical performance and cost data both for subsequent use in project development and periodical updating of the application guidance provided in Chapter 3.

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ATTN: Library
Huntsville
ATTN: Library (2)
ATTN: Chief, HNDED-SR
ATTN: Chief, HNDED-CS
ATTN: Chief, HNDED-ME
Lower Mississippi Valley
ATTN: Library
Ohio River
ATTN: Laboratory
ATTN: Library
ATTN: Chief, Engr Div

US Army Engineer Division
North Central
ATTN: Library
ATTN: Chief, Engr Div
Missouri River
ATTN: Library (2)
ATTN: Chief, Engr Div
ATTN: Laboratory
Southwestern
ATTN: Library
ATTN: Chief, SWDED-TM
South Pacific
ATTN: Chief, SPDED-TG
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ATTN: Chief, PODED-D
ATTN: Chief, PODED-P
ATTN: Chief, PODED-MP
ATTN: Chief, Engr Div
North Pacific
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Ft Gordon, GA 30905
Ft McClellan, AL 36201
Ft Knox, KY 40121
Ft Benjamin Harrison, IN 46216
Ft Leonard Wood, MO 65473
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Hathaway, Steve A
Application of the package controlled-air, heat-recovery solid waste incinerator on Army fixed facilities and installations. -- Champaign, IL : Construction Engineering Research Laboratory ; Springfield, VA : National Technical Information Service, 1979.
47 p. ; 27 cm. (Technical report ; E-151)

1. Refuse as fuel. 2. Incinerators. I. Title. II. Series: U.S. Army Construction Engineering Research Laboratory. Technical report ; E-151.